THE COST-EFFECTIVENESS OF RETROFITTING SANITARY FIXTURES IN RESTROOMS OF A UNIVERSITY BUILDING

A Thesis

by

BYOUNG HOON HWANG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2003

Major Subject: Construction Management

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Approved as to style and content by:

Paul K. Woods (Chair of Committee)	Ifte M. Choudhury (Member)
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ABSTRACT

The Cost-effectiveness of Retrofitting Sanitary Fixtures

in Restrooms of a University Building. (August 2003)

Byoung Hoon Hwang, B.S., Hanyang University, Korea

Chair of Advisory Committee: Dr. Paul K. Woods

This study measured the actual water consumption of sanitary fixtures installed in restrooms of a university building while most studies have been based on the manufacturer's reported flow rate. Furthermore, this study analyzed the appropriateness of retrofitting with low-consumption water closets and urinals based on the actual water consumption.

The purpose of this study is to analyze the cost-effectiveness of water savings from retrofitting water closets and urinals in restrooms of the Langford Architecture building A at Texas A&M University. The researcher directly measured the actual water-volume per flush of as-is, tune-up, low-consumption manual, and low-consumption automatic water closets and urinals. The data collected by these observations was analyzed, and the researcher evaluated the water savings of retrofitting water closets and urinals.

Finally, this study provides the actual water-consumption data of sanitary fixtures and proves that retrofitting with low-consumption fixtures can save on water costs. The results will present practical standards to facility managers and other building professionals and will also contribute to determining the feasibility of retrofitting water closets and urinals.

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INTRODUCTION

BACKGROUND

At the start of the new millennium, the world is faced with the certain realization that, through unsustainable population growth, economic expansion and rising per capita consumption, humanity is finally reaching the limits of renewable water resources (International Union for Conservation of Nature and Natural Resources, 2000). To overcome this water crisis and save water resources, some positive developments have been achieved in the construction industry. Water-efficient plumbing fixtures, such as low-flow toilets and showerheads, first became generally available to American consumers in the late 1980s. Subsequently, under the Energy Policy Act of 1992, the Congress established uniform national standards for the manufacture of these fixtures to promote conservation by residential and commercial water users. Consequently, all water-efficient plumbing fixtures must meet the standards for the maximum water consumption (United States General Accounting Office [USGAO], 2000).

Some studies have been conducted to measure water savings of water-efficient fixtures. However, most of the results show only the average values and ratios without considering the types of valve or the kinds of buildings. Furthermore, the results of some

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studies can be unreliable because the actual volume of water used by flushing sometimes varies from the manufacturer's reported flow rate (Vickers, 2001). Therefore, this study will analyze the water savings from retrofitting water closets and urinals with precise measurements, and evaluate the cost-effectiveness of applying low-consumption fixtures depending on the types of valves in a university building.

Facility Water Management

Facility managers are being forced to find new ways and means of reducing their operational costs due to increased pressure being exerted by top management for organization-wide cost reductions (Lewis, 2000). New technologies and approaches to design of building systems are making significant cost reduction possible. Such capital-improvement projects can deliver a satisfying payback and return on investment (Clarke, 1996). In facility water management, the time comes when the manager decides it is time to upgrade the system. The decision should be a logical one, driven by the life of the system and the scheduled replacement time of the system's component. Water conservation can be accomplished when upgrading by installing low-flow or ultra-low-flow toilets, low-flow urinals, and other water-saving equipment (Reid, 1996). Finally, the result of this study will present practical standards of low-consumption fixtures to facility managers and other building professionals and contribute to determining the availability of retrofitting water closets and urinals.

PURPOSE AND SCOPE

The purpose of this study is to analyze the cost-effectiveness of water savings from retrofitting water closets and urinals in restrooms of the Langford Architecture building A at Texas A&M University.

Objectives

- To measure the actual water consumptions of as-is, tune-up, low-consumption manual, and low-consumption automatic water closets and urinals applied to the restrooms of the Langford Architecture building A
- To analyze the cost-effectiveness of water savings from retrofitting water closets and urinals with low-consumption fixtures.

Limitations

This study is limited to water closets and urinals in the restrooms of the Langford Architecture building A at Texas A&M University. The building has four floors with rooftop offices and a basement.

Assumptions

- Only the water-volume per flush is the determining factor in water consumption of water closets and urinals—other conditions are equivalent.
- The water-volume per flush is subject to the types of valves in the water closets and urinals.

LITERATURE REVIEW

Increasing Environmental Awareness

Changing public attitudes regarding water issues notwithstanding, communities will probably have to contend with an increasing demand from their citizens for environmentally responsible action. A recent public opinion survey in Boulder, Colorado—a community noted for its strong environmental ethic—indicated that 78% of those responding were interested in water efficiency primarily because they believed wise use of the resource was important. Understanding people's increasing environmental values and concerns can help managers and planners gain support for implementing water efficiency program (Rocky Mountain Institute, 1991).

Improvement in Low-volume Fixtures

Improvements in water efficiency of toilets began in early 1980s as a result of refinements in the design of conventional gravity toilets, the introduction of new technologies and fixture designs, and local, state, and federal initiatives to promote water conservation. Although some of the early "low-flow" fixtures in the United States in the late 1980s received mixed reviews in terms of performance, manufactures have improved the design and performance of low-volume toilets so that consumers can now choose from a large number of reliable products (Vickers, 2001).

Regulations; The Energy Policy Act of 1992

The Energy Policy Act of 1992 established water conservation standards for the manufacture of four types of plumbing fixtures: toilets, kitchen and lavatory faucets, showerheads, and urinals. With limited exceptions, the standards apply to all models of the fixtures manufactured after January 1, 1994. (see Table 1).

Table 1

National water efficiency standards (Vickers, 2001)

Fixture type	Maximum allowable water use
Toilets, including gravity tank-type toilets, flushometer tank toilets, and electromechanical hydraulic toilets	1.6 gallons per flush (gpf)
Urinals	1.0 gallon per flush (gpf)

Under the Department of Energy's regulations, water-efficient plumbing fixtures must meet the standards for maximum water consumption. For each model of a regulated plumbing fixture, manufacturers and private labelers must submit a compliance statement to the Department to certify that the model complies with the applicable water conservation standard and that all required testing has been conducted according to the test requirements prescribed in the regulations (USGAO, 2000).

Low-consumption Water Closets

Low-volume toilets, also referred to by the terms low-flow, low-flush, low-consumption, ultralow-flush, and ultralow-volume, typically use 1.6 gallons per flush (gpf) or less.

Low-volume toilets are available in the same operating designs as high-volume fixtures. Similarly, Low-volume toilets can be either floor- or wall-mounted and are available in a range of styles, sizes, and colors. Low-volume toilets can be installed to replace high-volume toilets in residential and nonresidential settings, with a few exceptions. Three basic types of low-volume toilets are commonly available, along with several alternative ultra-efficient designs.

In a office, replacing a 3.5 gpf toilets with a 1.6 gpf fixture will save an estimated 1.9 gallons per capita per day (gpcd) for males and 5.7 gpcd for females, the equivalent of annual water savings of 494 gallons per capita per day (gpcy), respectively. A study of more 200 gpf pressurized-tank toilets that replaced high-volume (2.5 gpf and higher) fixtures in a variety of commercial properties in two California communities, the city of Petaluma and Rohnert Park, Found that the average savings per toilet was 26 gallons per day (gpd) (Vickers, 2001).

Low-consumption Urinals

Low-volume, flushometer-valve urinals that use 1.0 gpf or less can be installed to replace high-volume, flush-valve fixtures, often with no modifications to the bowl or to wall or floor connections. In some cases only the flush valve needs to be replaced to lower the flow rate to 1.0 gpf. Low-volume, flush-valve urinals operate the same way as high-volume, flush-valve urinals and toilets, except that the diaphragm orifice in the valve has a smaller diameter. Installation of low-volumes, flush-valve urinals to replace other types of high-volume requires removal of the old fixture and flushing apparatus and installation of an entirely new fixture and valve.

Water use by urinals in office restrooms for males is estimated to be about 2.0 gpcd when a 1.0 gpf fixture is installed and 3.0 to 9.0 gpcd when high-volume fixture are in use. Water use by toilets is also a factor in office restrooms for males. The frequency of urinal flushing by males in office lavatories is estimated to be about two times per workday (Vickers, 2001).

Water Flow Meter

All flow meters work on the basic principles of fluid mechanics. A type of common meter utilized in facility water system is the disk meter. A disk meter more accurately measures flows by using a flat disk that sits in the meter housing on an angle to the flow. As the water passes through the meter, the disk turns, similar to the propeller. The turning disk is geared to a clock face and the gears are designed to provide numbers that correspond directly to the number of gallons used (Reid, 1996).

EXPERIMENT METHOD

Fixtures in Restrooms

The experiment was conducted on water closets and urinals in restrooms of the Langford Architecture building A at Texas A&M University. The building has a men's and women's restroom on each of the four floors. There are two water closets in each men's room and four water closets in each women's room for a total of twenty-four water closets in the building. Each men's restroom has three urinals for a total of twelve in the building.

The fixtures were named *m* for those in the men's restrooms and *w* for those in the women's restrooms. Water closets are *w* and urinals are *u*. The fixtures are numbered clockwise in each restroom. A number prefix was used to indicate the floor. The fixture *2mw1* identifies the fixture as being on the second floor, men's restroom, and water closet number one. Figure 1 shows the men's restroom layout in the building. Figure 2 shows the women's restroom layout (Parker, 2002).

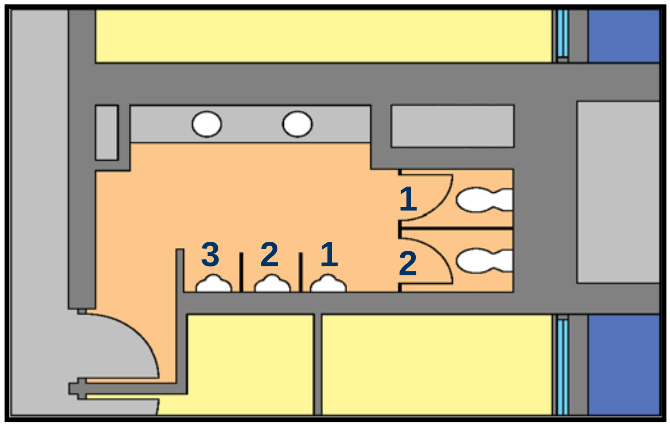

Figure 1: Men’s restroom layout in the building (Parker, 2002)

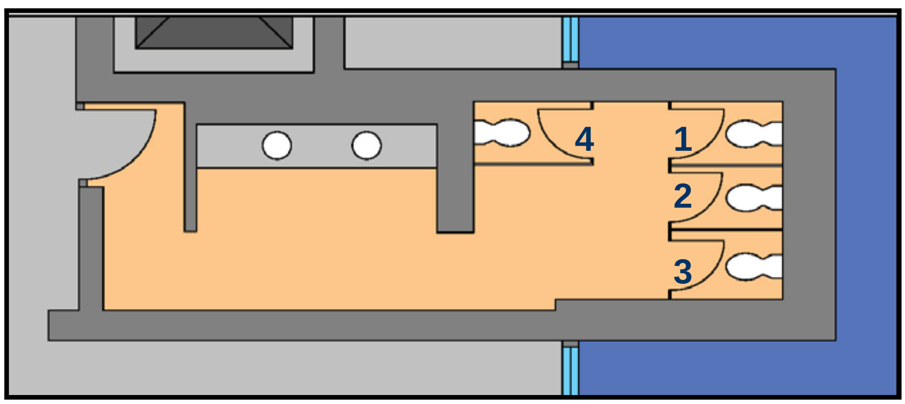

Figure 2: Women’s restroom layout in the building (Parker, 2002)

Water Closets and Urinals

The researcher conducted a pilot test on as-is status, and measured the water-volume per flush of tune-up, low-consumption manual, and low-consumption automatic water closets and urinals with retrofitting. In the as-is phase, there were originally twenty-four water closets (3.5 gpf) and twelve urinals (1.6 gpf). Figure 3 shows photos of a water closet fixture and a urinal fixture in the as-is phase in the building. These fixtures were a kind of flushometer-valve toilets—a tankless toilet with the flush valve attached to a pressurized water supply pipe (see Appendix A).

Figure 3: Water closet and urinal in the as-is phase

After the as-is phase experiment, in tune-up phase the original valves of water closets and urinals were replaced partly with new diaphragms, handles, and vacuum breakers (see Figure 4). However, chinas and other plumbing systems had the same status as the as-is phase. Finally, the standard of the water closets was replaced to 4.5 gpf, but urinals' were the same 1.6 gpf as in the as-is phase.

Figure 4: Valve in the tune-up phase

After the tune-up phase, low-consumption valves and chinas were installed, but other plumbing systems had the same status as before. Figure 5 and 6 show water closet and urinal fixtures in the low-manual and low automatic phases. They were also a kind of flushometer-valve toilets, and the standards of the water closets and urinals were replaced to 1.6 and 1.0 gpf.

Figure 5: Water closet and urinal in the low-manual phase

Figure 6: Water closet and urinal in the low-automatic phase

Measurement Methods

A plug or balloon was used to stop up the waterway of the fixtures. After flushing with stopping up the waterway, the researcher measured directly the actual water-volume per flush (gpf) and repeated this over five times on each for all fixtures on each phase (see Figure 7).

Figure 7: Measurement methods

Water Flow Meter

After a pilot test on as-is phase, a water-flow meter, Rosemont 8705, was installed to obtain reliable data in the basement of the Langford Architecture building A (see Figure 8). The water meter was read before and after flushing the water closets and urinals while keeping all other fixtures and water appliances turned off.

Figure 8: Water meter in the basement

RESULTS OF WATER CLOSETS

The researcher conducted a pilot test on water closets in the as-is status, and then measured the water-volume per flush of the tune-up, low-consumption manual, and low-consumption automatic water closets with retrofitting. The researcher repeated the observations with the plug or balloon measurement method for each water closet fixture in restrooms of the Langford Architecture building A at Texas A&M University. The collected data in the water closets is categorized in Table 2 by measurement methods and phases.

Table 2

Collected data in water closets

Water Closet (24 EA)	Old water closet fixtures (china and valve)		New water closet fixtures (china and valve)	
Phase (Valve type) / Measurement	**Pilot Test (As-is)**	**Tune-up**	**Low-Manual**	**Low-Auto**
	(3.5 gpf)	**(4.5 gpf)**	**(1.6 gpf)**	**(1.6 gpf)**
Plug	10 times for each of all fixtures	5 times for each of all fixtures	5 times for each of all fixtures with plug or balloon	10 times for each of selected 8 fixtures with plug or balloon
Balloon	No data	5 times for each of all fixtures		
Water-flow Meter	No data	5 times for each of all fixtures with plug	5 times for each of all fixtures with plug or balloon	10 times for each of selected 8 fixtures with plug or balloon
		5 times for each of all fixtures with balloon		
		5 times for each of all fixtures without measurement	5 times for each of all fixtures without measurement	10 times for each of selected 16 fixtures without measurement

PILOT TEST:AS-IS PHASE OF WATER CLOSETS

First, the researcher conducted a pilot test on the water closets (02/08/2002~02/28/2002, 04/18/2002~05/08/2002).

a. The experimental objects were made up of twenty-four water closets (3.5 gpf) in an unmodified condition (as-is). The researcher directly measured the actual water-volume per flush with plug method, and repeated this ten times for all the fixtures in the restrooms of the Langford Architecture building A.

b. Three water closets were different shapes, and they were not able to be measured correctly: 1ww3, 2ww1, and 4ww2. Therefore, those values were removed on the pilot test.

Findings in the Pilot Test: As-is Phase

a. The measured mean, 3.305 gpf, was less than the standard 3.5 gpf (see Table 3). Moreover, statistically, there was a significant difference between the mean and the standard. To compare them, a one sample T-test was conducted:

H_o : µ as-is = 3.5 gpf,

H_a : µ as-is $\neq$ 3.5 gpf.

The null hypothesis was rejected because p-value (.005) < .05 (see Table 4).

Table 3

Descriptive statistics - as-is phase of water closets

		Statistic
ASIS_WC	Mean	3.3050
	Median	3.4483
	Variance	1.051
	Std. Deviation	1.02499
	Minimum	1.45
	Maximum	4.87
	Range	3.42

Table 4

T-test - measured data vs. standard (3.5 gpf)

	Test Value = 3.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
As-is WC	-2.808	209	.005	-.1950	-.3320	-.0581

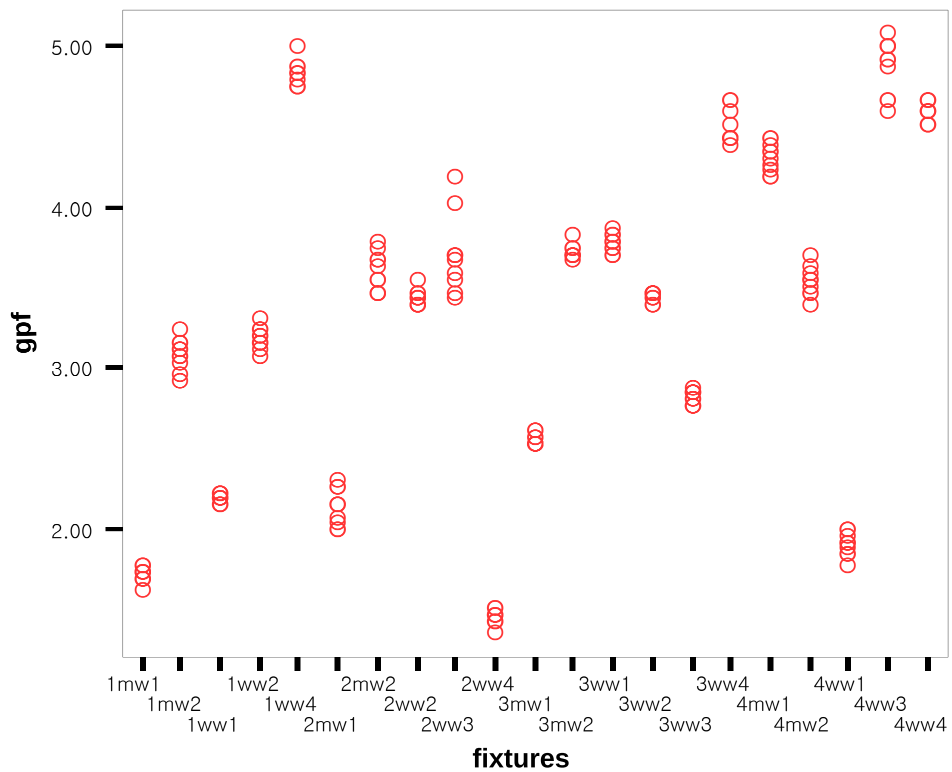

Figure 9: Scatter plot - measured data (plug method)

b. The values between fixtures had considerable differences—standard deviation and range were significant (see Table 3 and Figure 9). To define another measure of variability, coefficient of variation (CV) was applied. The coefficient of variation (CV) measures the variability in the values in a population relative to the magnitude of the population mean. Thus, the CV is the standard deviation of the population expressed in units of μ.

Coefficient of variation (CV) of as-is phase was 31.013 %:

CV = 100 (s / $|\bar{y}|$)% = 100 (1.0250 / 3.3050)%. The result was assumed because original fixtures had not been on a timely management service.

c. After the as-is phase, a water-flow meter, Rosemont 8705, was installed to obtain reliable data in the basement of the Langford Architecture building A.

TUNE-UP PHASE OF WATER CLOSETS

Second, the researcher collected data on the tune-up phase of the water closets (09/26/2002~10/09/2002).

a. New diaphragms, handles, and vacuum breakers were installed in the original valves of all water closets. However, chinas and other plumbing systems had the same status as the as-is phase. Finally, the standard of the water closets was replaced to 4.5 gpf.

b. The researcher measured directly the actual water-volume per flush with plug and balloon methods and repeated it five times for all twenty-four fixtures. At the same time, the water meter was read.

c. Additionally, the water meter was read five times for all twenty-four fixtures, when the plug or balloon method was not applied to china, to analyze whether the methods were effective in measuring meter values.

d. Three water closets had different shapes, and they were difficult to measure correctly: 1ww3, 2ww1, and 4ww2. Therefore, the values were also removed on tune-up phase.

<u>Findings in Tune-up Phase</u>

a. Plug and balloon measurement methods had similar means, standard deviations, and similar graphs (see Table 5 and Figure 10). Moreover, statistically, there was no significant difference between the measurement methods of plug and balloon in the tune-up phase of the water closets. A paired T-test was conducted:

H_o : µ plug = µ balloon,

H_a : µ plug $\neq$ µ balloon.

The null hypothesis was accepted because p-value (.219) > .05 (see Table 6). Therefore, both plug and balloon methods were reliable, and there was no need to distinguish between them.

Table 5

Descriptive statistics - plug and balloon methods

		Statistic
PLUG	Mean	4.1521
	Median	4.4014
	Variance	.407
	Std. Deviation	.63799
	Minimum	2.78
	Maximum	5.27
	Range	2.49
BALLOON	Mean	4.1949
	Median	4.2275
	Variance	.389
	Std. Deviation	.62334
	Minimum	2.78
	Maximum	5.29
	Range	2.51

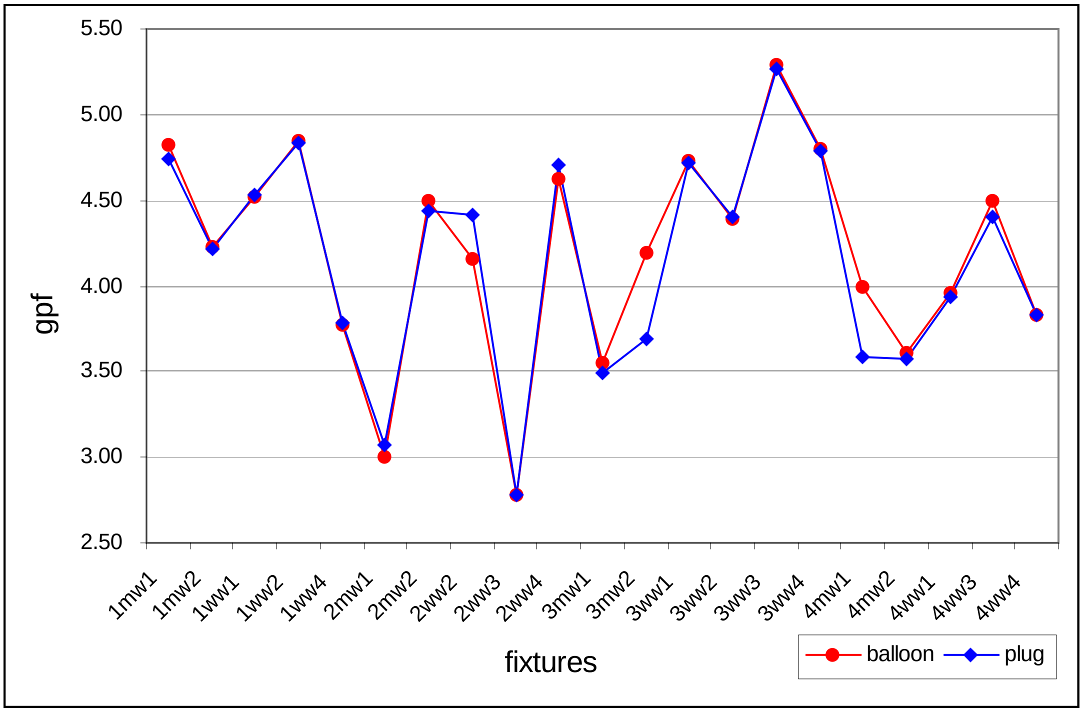

Figure 10: Graph - balloon vs. plug methods

Table 6

T-test - plug vs. balloon methods

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
PLUG_TUN – BALL_TUN	−.0429	.15481	.03378	−.1133	.0276	−1.269	20	.219

b. The mean, 4.17 gpf, in the tune-up phase of the water closets was less than the standard 4.5 gpf (see Table 7). Moreover, statistically, there was a significant difference between the mean and the standard. To compare them, a one sample T-test was conducted:

H_o : µ tune-up = 4.5 gpf,

H_a : µ tune-up $\neq$ 4.5 gpf.

The null hypothesis was rejected because p-value (.000) < .05 (see Table 8).

Table 7

Descriptive statistics - tune-up phase of water closets

		Statistic
Tuneup	Mean	4.1735
	Median	4.2864
	Variance	.392
	Std. Deviation	.62595
	Minimum	2.78
	Maximum	5.28
	Range	2.50

Table 8

T-test - measured data vs. standard (4.5 gpf)

	Test Value = 4.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Tune-up WC	-7.592	209	.000	-.3265	-.4113	-.2417

c. Figure 11 shows that the difference between fixtures is less than in the as-is phase. It is assumed that this is due to the original fixtures receiving a tune-up. Coefficient of variation (CV) of tune-up phase was 14.999 %:

CV = 100 (s / $|\bar{y}|$)% = 100 (0.6260 / 4.1735)%. It was quite less than the as-is phase, 31.013 %.

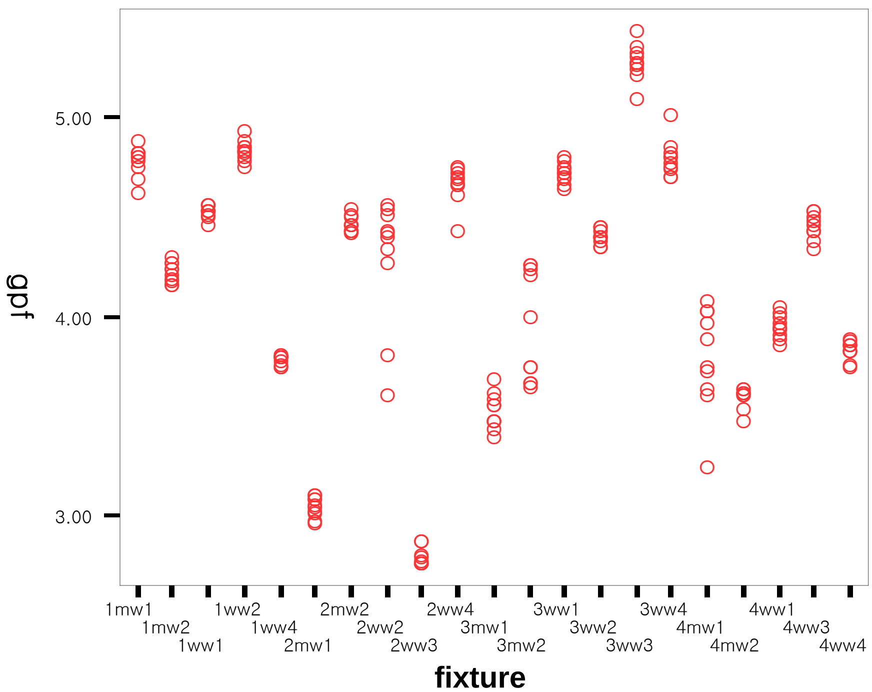

Figure 11: Scatter plot - measured data

d. The mean of the water meter (4.034 gpf) was less than the directly measured means (4.17 gpf) with plug and balloon methods because the water meter was not sensitive to small water volume (see Table 7 and 9). A paired T-test was conducted:

H_o : µ meter = µ measure,

H_a : µ meter $\neq$ µ measure.

The null hypothesis was rejected because p-value (.000) < .05 (see Table 10). Therefore, the water meter was not appropriate as a measurement method.

Table 9

Descriptive statistics - water meter

		Statistic
METER	Mean	4.0343
	Median	4.2300
	Variance	.423
	Std. Deviation	.65019
	Minimum	2.52
	Maximum	5.10
	Range	2.58

Table 10

T-test - water meter vs. measured data

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
METER – MEASURE	−.1399	.15613	.02409	−.1886	−.0913	−5.808	41	.000

e. However, the water meter was reliable in measuring the water-volume per flush. Figure 12 shows that the water meter and directly measured values in the tune-up phase have similar graphs. The meter values and the measured values are moving together in a constant rate. Moreover, a regression model showed that they had a relationship (see Figure 13 and Table 11). The regression model had a high R-square and the test results were acceptable (see Table 12 and 13).

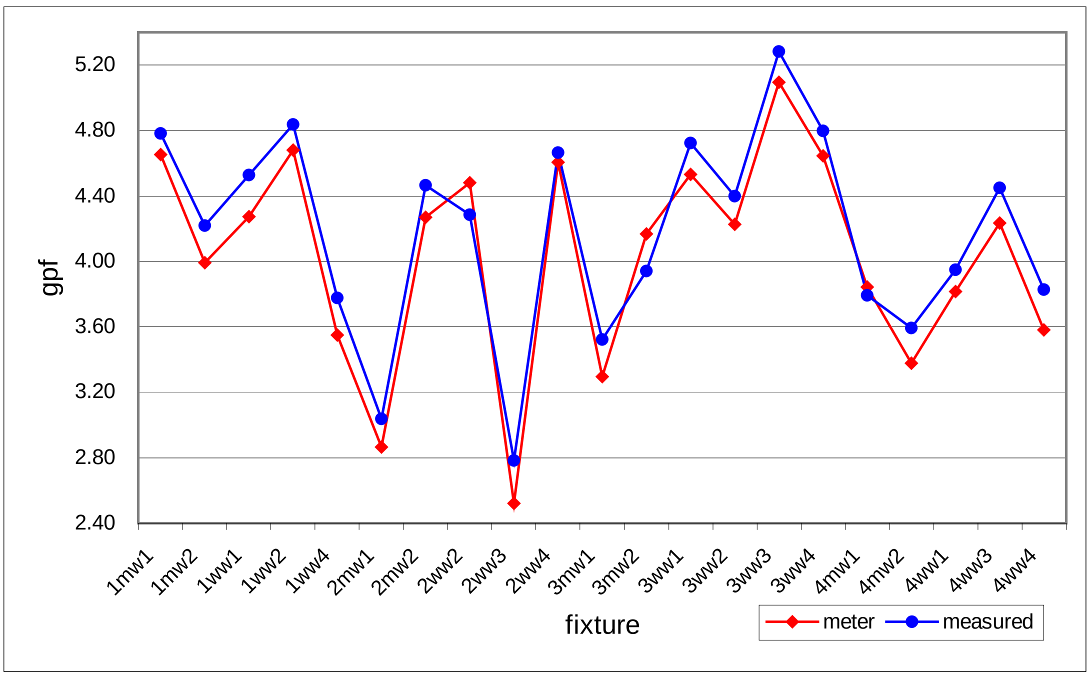

Figure 12: Graph - water meter vs. measured data

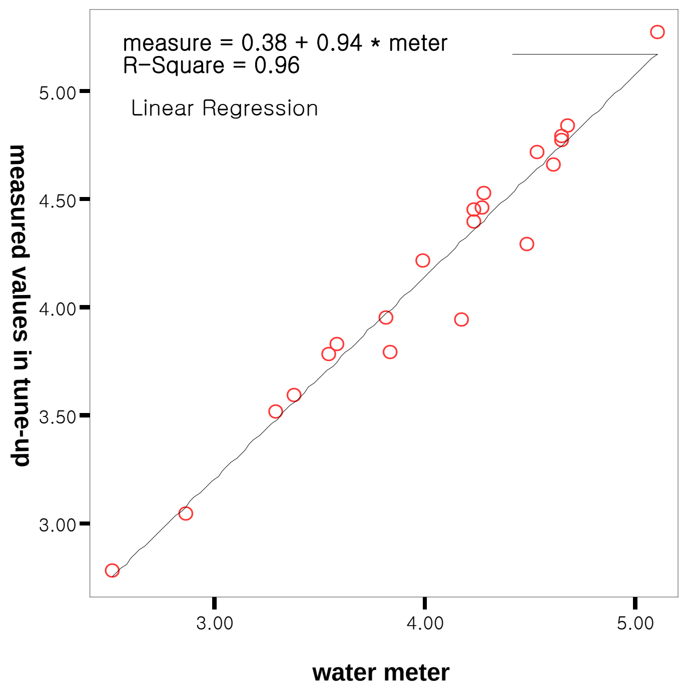

*Figure 13:*Scatter plot - water meter vs. measured data

Table 11

Coefficients - water meter vs. measured data

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.376	.189		1.991	.061
	METER	.941	.046	.978	20.337	.000

Table 12

Model summary - water meter vs. measured data

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.978[a]	.956	.954	.13459

a. Predictors: (Constant), METER

Table 13

ANOVA table - water meter vs. measured data

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.491	1	7.491	413.578	.000[a]
	Residual	.344	19	.018		
	Total	7.835	20			

a. Predictors: (Constant), METER

f. There was no difference between results with and without measurement methods in the water meter. Therefore, the test with plug or balloon method had no effect on the value of the water meter. To prove it, a Bonferroni test was conducted:

H_o : µ meter only = µ meter with plug = µ meter with balloon,

H_a : at least one of the means differs from rest.

The null hypothesis was accepted (see Table 14).

Table 14

Bonferroni test - with and without methods in water meter

Dependent Variable: MET_VALU

	(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Bonferroni	1.00	2.00	-.0021	.20247	1.000	-.5008	.4966
		3.00	-.0085	.20247	1.000	-.5071	.4902
	2.00	1.00	.0021	.20247	1.000	-.4966	.5008
		3.00	-.0064	.20247	1.000	-.5051	.4923
	3.00	1.00	.0085	.20247	1.000	-.4902	.5071
		2.00	.0064	.20247	1.000	-.4923	.5051

1: meter only, 2: meter with plug, 3: meter with balloon

LOW-MANUAL PHASE OF WATER CLOSETS

Third, the researcher collected data on the low-manual phase of water closets (10/14/2002~10/27/2002).

a. New low-consumption manual valves and chinas were installed in the restrooms of the Langford Architecture building A. However, other plumbing systems had the same status as before. They all had the same shape of china and the same type of valves, and the standard of the water closets was 1.6 gpf.

b. The researcher measured the actual water-volume per flush with plug or balloon methods and repeated it five times for all twenty-four fixtures. At the same time, the water meter was read.

c. Additionally, the water meter was read five times for all twenty-four fixtures, when the measurement method was not applied to china, in order to analyze whether the method was effective in measuring meter values.

Findings in Low-manual Phase

a. The mean, 1.599 gpf, in the low-manual phase of the water closets was same as the standard 1.6 gpf (see Table 15). Statistically, there was no significant difference between the mean and the standard. To compare them, a one sample T-test was conducted:

H_o : µ low-manual = 1.6 gpf,

H_a : µ low-manual $\neq$ 1.6 gpf.

The null hypothesis was accepted because p-value (.962) > .05 (see Table 16).

Table 15

Descriptive statistics - low-manual phase of water closets

		Statistic
LowManual_WC	Mean	1.5990
	Median	1.5657
	Variance	.053
	Std. Deviation	.22959
	Minimum	.94
	Maximum	1.96
	Range	1.02

Table 16

T-test - measured data vs. standard (1.6 gpf)

	Test Value = 1.6					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Low-manual WC	-.047	119	.962	-.0010	-.0424	.0404

b. 2ww1 had considerable difference from the others (see Figure 14). However, coefficient of variation, 14.358 %, was less than the as-is and tune-up phases:

CV = 100 (s / $|\bar{y}|$)% = 100 (0.2296 / 1.5990)%.

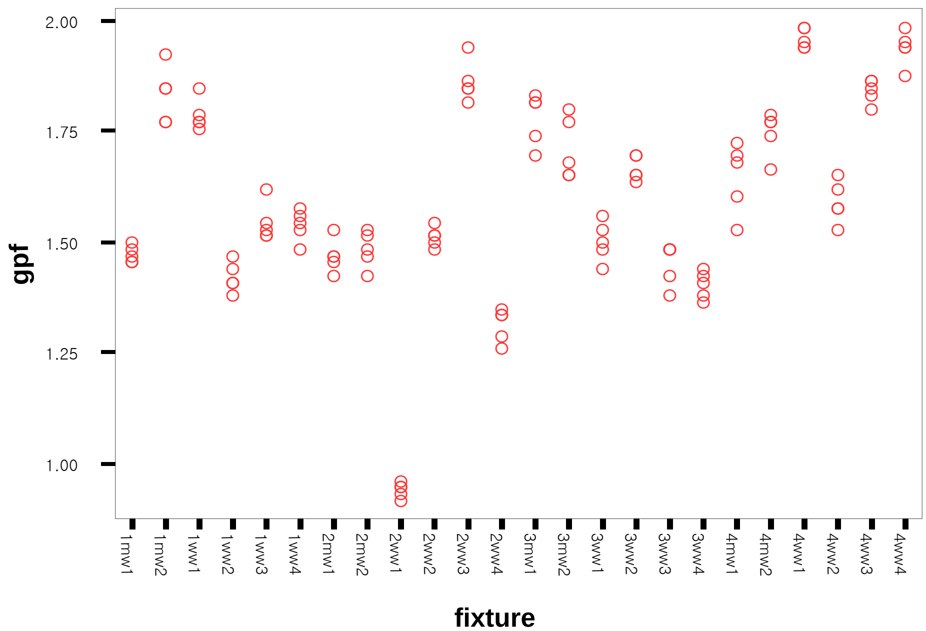

Figure 14: Scatter plot - measured data

c. The mean of the water meter (1.404 gpf) was less than the directly measured mean (1.599 gpf) with plug and balloon methods because the water meter was not sensitive to small water volume —It is the same result as the tune-up phase (see Table 17). A paired T-test was conducted:

H_o : µ meter = µ measure,

H_a : µ meter ≠ µ measure.

The null hypothesis was rejected because p-value (.000) < .05 (see Table 18). Therefore, the water meter was not appropriate as a measurement method.

Table 17

Descriptive statistics - water meter

		Statistic
METER	Mean	1.4038
	Median	1.3990
	Variance	.048
	Std. Deviation	.21874
	Minimum	.70
	Maximum	1.71
	Range	1.01

Table 18

T-test - water meter vs. measured data

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
METER – MEASURED	-.1952	.07449	.01520	-.2266	-.1637	-12.84	23	.000

d. However, the water meter was reliable in measuring the water-volume per flush. Figure 15 shows that the water meter and directly measured values in the low-manual phase have similar graphs—It is same result as the tune-up phase. The meter values and the measured values are moving together in a constant rate. Moreover, a regression model showed that they had a relationship (see Figure 16 and Table 19). The regression model had a high R-square and the test results were acceptable (see Table 20 and 21)

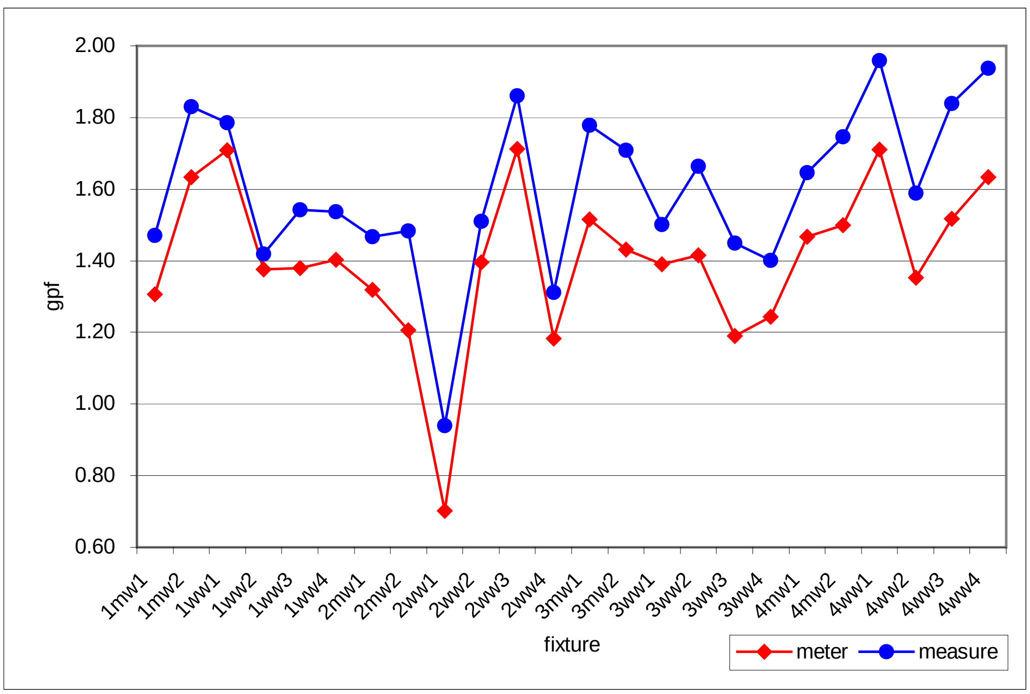

Figure 15: Graph - water meter vs. measured data

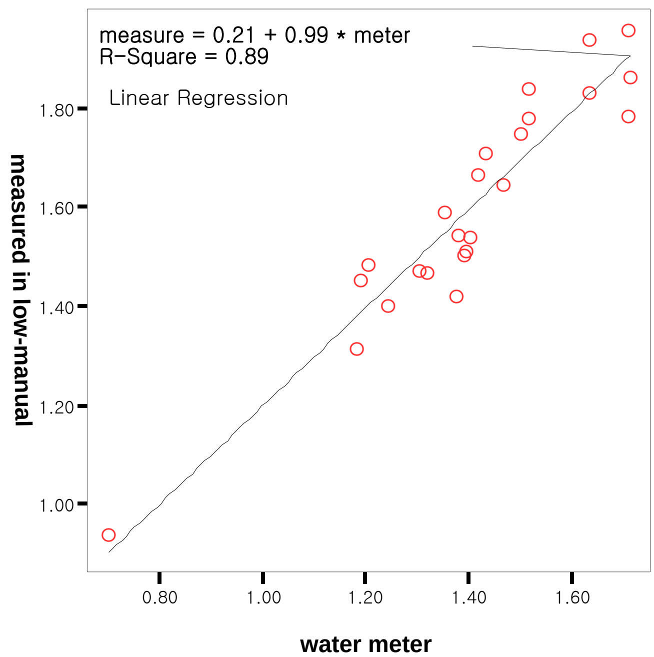

Figure 16: Scatter plot - water meter vs. measured data

Table 19

Coefficients - water meter vs. measured data

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.205	.103		1.991	.059
	METER	.993	.073	.946	13.679	.000

Table 20

Model summary - water meter vs. measured data

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.946[a]	.895	.890	.07614

a. Predictors: (Constant), METER

Table 21

ANOVA table - water meter vs. measured data

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.085	1	1.085	187.113	.000[a]
	Residual	.128	22	.006		
	Total	1.212	23			

a. Predictors: (Constant), METER

e. There was no difference between results with and without measurement methods in the water meter. Accordingly, the test with plug or balloon method has no effect on the value of the water meter—same result as the tune-up phase.

A paired T-test was conducted:

H_o : µ meter only = µ meter with measurement,

H_a : µmeter only $\neq$ µmeter with measurement.

The null hypothesis was accepted because p-value (.085) > .05 (see Table 22).

Table 22

T-test - with and without methods in water meter

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Meter only – with measurement	−.0157	.04262	.00870	−.0337	.0023	−2	23	.085

LOW-AUTOMATIC PHASE OF WATER CLOSETS

Fourth, the researcher collected data on the low-automatic phase of water closets (11/11/2002~11/26/2002).

a. New low-consumption automatic valves were installed on the chinas in the low-manual phase instead of low-consumption manual valves. However, chinas and other plumbing systems had the same status as the low-manual phase. They all had the same shape of china and the same type of valves, and the standard of the water closets was 1.6 gpf.

b. The researcher measured the actual water-volume per flush with plug or balloon methods and repeated it ten times for randomly selected eight fixtures. At the same time, the water meter was read.

c. The water meter was read ten times for each of the sixteen fixtures that were not directly measured, when plug or balloon method was not applied to china, in order to predict directly measured values.

<u>Findings in Low-automatic Phase</u>

a. It was proven that there was a relationship between the water meter and measured values in the tune-up and low-manual phases. To predict the actual water-volume values of the sixteen fixtures that were not measured directly, the researcher conducted a regression between the directly measured eight fixtures and the water meter.

The regression model was

Measure low-auto = Bo + B1 Meter low-auto

= 0.415 + .921 * Meter low-auto (see Figure 17 and Table 23).

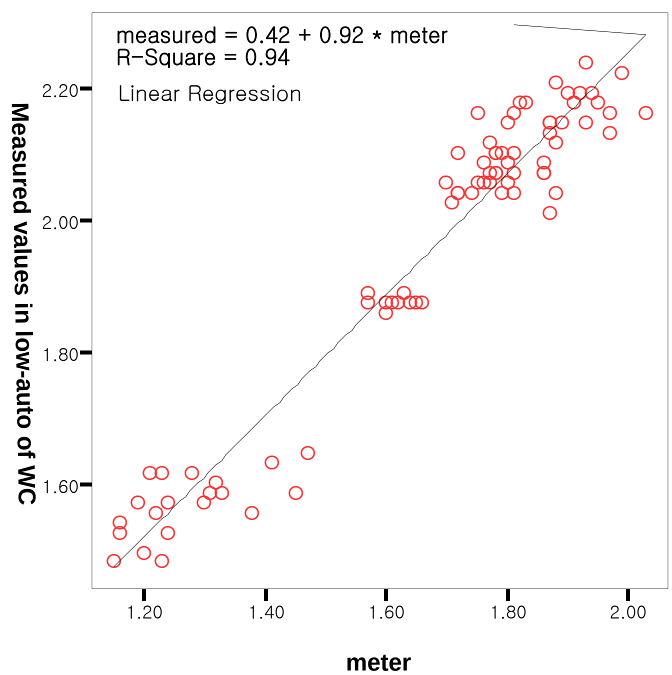

Figure 17: Scatter plot - water meter vs. measured data

Table 23

Coefficients - water meter vs. measured data

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.415	.045		9.237	.000
	METER	.921	.027	.969	34.495	.000

Table 24

Model summary - water meter vs. measured data

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.969[a]	.938	.938	.05965

a. Predictors: (Constant), METER

Table 25

ANOVA table - water meter vs. measured data

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.234	1	4.234	1189.918	.000[a]
	Residual	.278	78	.004		
	Total	4.511	79			

a. Predictors: (Constant), METER

The regression model had a high R-square and the test results were acceptable (see Table 24 and 25). Residual was also normally distributed (Figure 18 and Table 26).

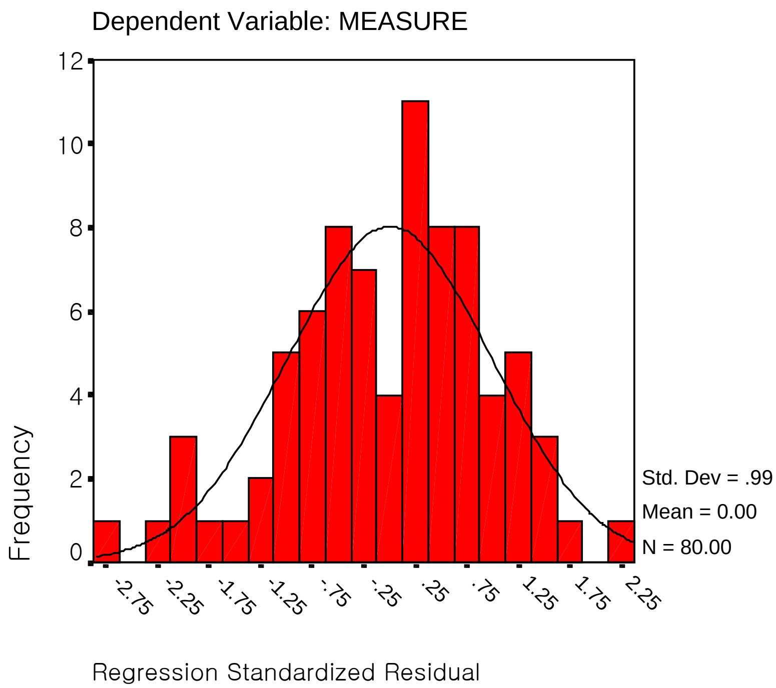

Figure 18: Residual histogram - water meter vs. measured data

Table 26

Normality test - water meter vs. measured data

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Standardized Residual	.090	80	.162	.985	80	.487

a. Lilliefors Significance Correction

b. The measured mean, 1.98 gpf, in the low-automatic phase of water closets was more than the standard 1.6 gpf (see Table 27). Moreover, there was a significant difference between the mean and the standard. A one sample T-test was conducted:

H_o : µ low-auto = 1.6 gpf,

H_a : µ low-auto $\neq$ 1.6 gpf.

The null hypothesis was rejected because p-value (.000) < .05 (see Table 28).

Table 27

Descriptive statistics - low-automatic phase of water closets

		Statistic
LOW_AUTO	Mean	1.9802
	Median	2.0512
	Variance	.066
	Std. Deviation	.25768
	Minimum	1.52
	Maximum	2.37
	Range	.85

Table 28

T-test - measured data vs. standard (1.6 gpf)

	Test Value = 1.6					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Low-auto WC	22.994	239	.000	.3802	.3476	.4128

c. Figure 19 shows that the difference between the fixtures is less significant than in other phases. Coefficient of variation, 13.014 %, was the lowest value in the water closet phases: CV = 100 (s / $|\bar{y}|$)% = 100 (0.2577 / 1.980)%.

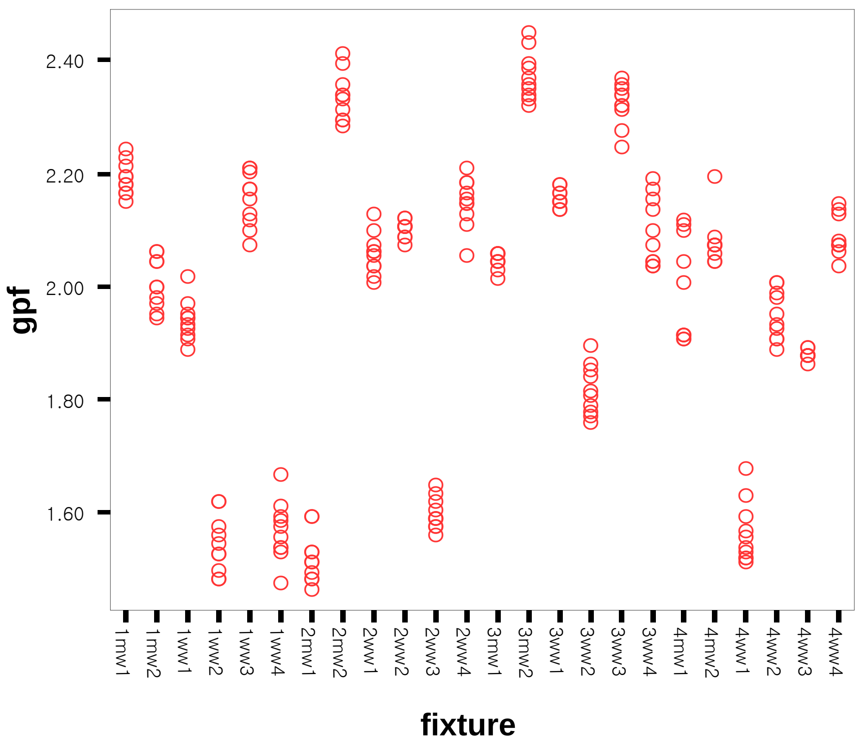

Figure 19: Scatter plot - measured data

SUMMARY OF WATER CLOSETS

a. The researcher compared the water-volume per flush of all phases in the water closets. Figure 20 shows the means in the water closets. The result of the mean values is Tune-up (4.174 gpf) > As-is (3.305 gpf) > Low-auto (1.980 gpf) > Low-manual (1.599 gpf). Table 29 shows the comparative water-volume of other phases when it is assumed that the mean of as-is phase is 100%.

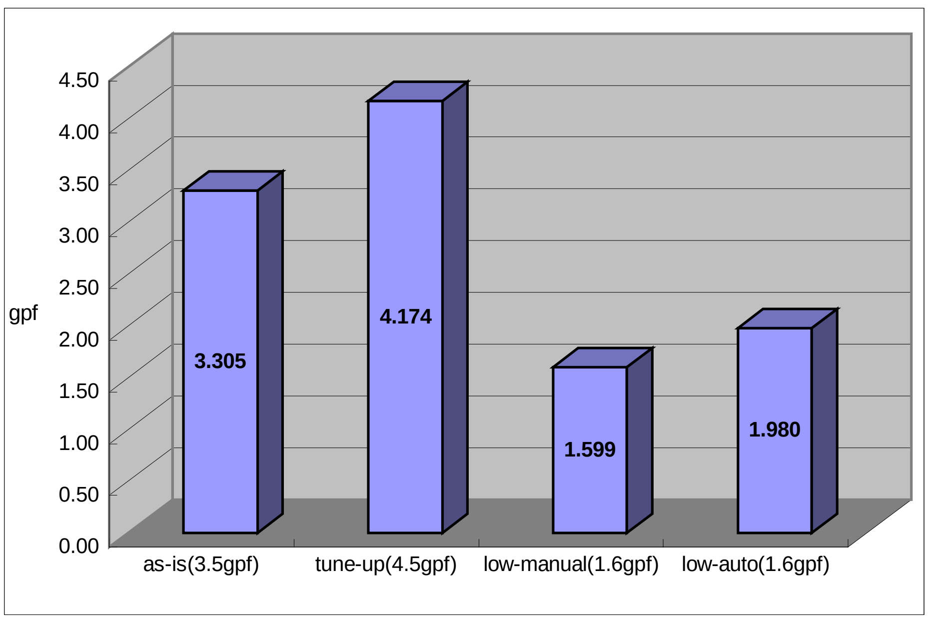

Figure 20: Graph - means in water closets

Table 29

As-is vs. comparative values of other phases in water closets

Phase	**As-is**	**Tune-up**	**Low-manual**	**Low-auto**
Mean	3.305 gpf	4.174 gpf	1.599 gpf	1.980 gpf
Each / As-is (%)	**100 %**	**126.29 %**	**48.381 %**	**59.91 %**

b. However, statistical analysis has a different result.

A Bonferroni test was conducted:

H_o : µ as-is = µ tune-up = µ low-manual = µ low-auto,

H_a : at least one of the means differs from rest.

The null hypothesis was rejected (see Table 30).

The result of statistics analysis is

Tune-up > As-is > Low-manual = Low-automatic.

Table 30

Bonferroni test - water closets

Dependent Variable: VAR00002
Bonferroni

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.8685*	.18730	.000	-1.3744	-.3627
	3.00	1.7059*	.18135	.000	1.2162	2.1957
	4.00	1.3244*	.18135	.000	.8346	1.8142
2.00	1.00	.8685*	.18730	.000	.3627	1.3744
	3.00	2.5745*	.18135	.000	2.0847	3.0642
	4.00	2.1929*	.18135	.000	1.7032	2.6827
3.00	1.00	-1.7059*	.18135	.000	-2.1957	-1.2162
	2.00	-2.5745*	.18135	.000	-3.0642	-2.0847
	4.00	-.3815	.17520	.193	-.8547	.0916
4.00	1.00	-1.3244*	.18135	.000	-1.8142	-.8346
	2.00	-2.1929*	.18135	.000	-2.6827	-1.7032
	3.00	.3815	.17520	.193	-.0916	.8547

*. The mean difference is significant at the .05 level.

1: As-is, 2: Tune-up, 3: Low-manual, 4:Low-automatic

c. Most phases of the water closets have different actual water-volumes than the standards (see Figure 21). The as-is, tune-up and low-automatic phases show significant differences statistically between the standards and the actual water-volumes of flushing (Table 31).

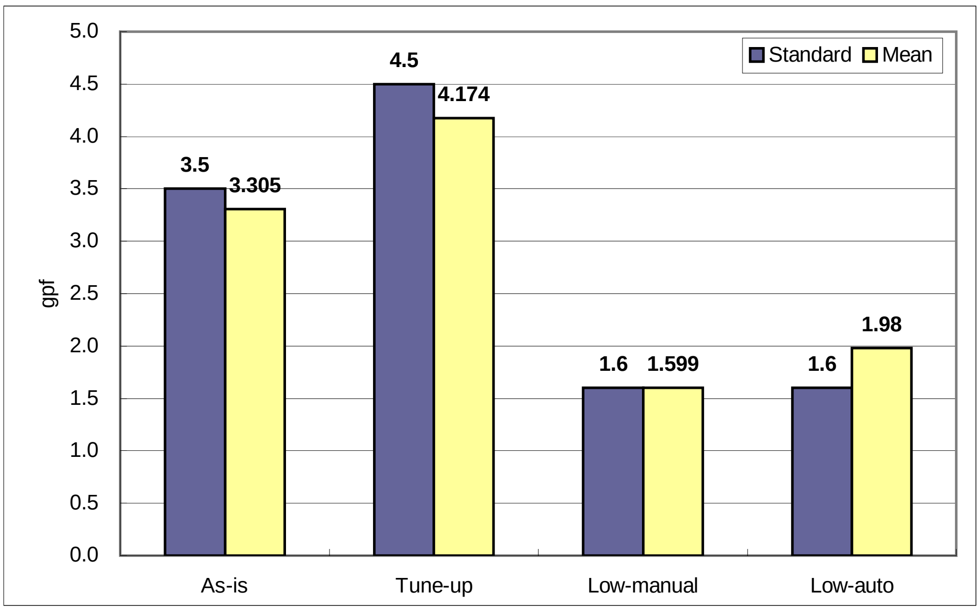

Figure 21: Graph - measured mean vs. standard in water closets

Table 31

The standard vs. measured means in water closets

Phase	**As-is**	**Tune-up**	Low-manual	**Low-auto**
Mean	**3.305 gpf**	**4.174 gpf**	1.599 gpf	**1.980 gpf**
Standard	**3.5 gpf**	**4.5 gpf**	1.6 gpf	**1.6 gpf**
Mean / Std. (%)	**94.43 %**	**92.76 %**	99.94 %	**123.75 %**
Sig. *(2-tailed)*	**.005**	**.000**	.962	**.000**

d. There is a tendency in low-consumption fixtures to have a lower coefficient of variance (CV). New fixtures in the low-manual and low-automatic phases have a low CV, but old fixtures in the as-is phase have a high rate. The tune-up phase also has a low rate (see Figure 22 and Table 32). It is assumed that the results are related to the management status of the fixtures.

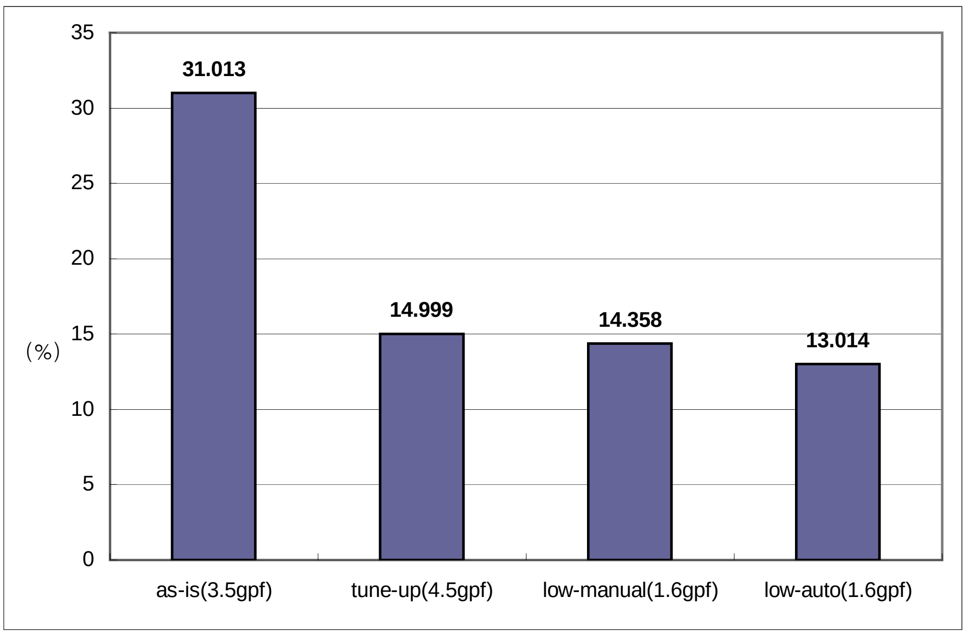

Figure 22: Graph - coefficient of variance in water closets

Table 32

Coefficient of variance in water closets

Phase	As-is	Tune-up	Low-manual	Low-auto
Std. Deviation	1.0245	0.6260	0.2296	0.2577
Mean	3.305 gpf	4.174 gpf	1.599 gpf	1.980 gpf
CV	**31.013 %**	**14.999 %**	**14.358 %**	**13.014 %**

RESULTS OF URINALS

The researcher conducted a pilot test on urinals in the as-is status, and measured the water-volume per flush of the tune-up, low-consumption manual, and low-consumption automatic urinals with retrofitting. The researcher repeated the observations with the plug or balloon measurement method for each urinal fixture in restrooms of the Langford Architecture building A at Texas A&M University. The data collected in the urinals is categorized in Table 33 by measurement methods and phases. Basically, the experiment method and procedure for the urinals was similar to those of water closets.

Table 33

Collected data in urinals

<table>
<tr><th>Urinal
(12 EA)</th><th colspan="2">Old urinal fixtures
(china and valve)</th><th colspan="2">New urinal fixtures
(china and valve)</th></tr>
<tr><th rowspan="2">Phase (Valve type)
Measurement</th><th>Pilot Test (As-is)</th><th>Tune-up</th><th>Low-Manual</th><th>Low-Auto</th></tr>
<tr><th>(1.5 gpf)</th><th>(1.5 gpf)</th><th>(1.0 gpf)</th><th>(1.0 gpf)</th></tr>
<tr><td>Plug</td><td>10 times for each of all fixtures</td><td>5 times for each of all fixtures</td><td rowspan="2">5 times for each of all fixtures with plug or balloon</td><td rowspan="2">10 times for each of selected 4 fixtures with plug or balloon</td></tr>
<tr><td>Balloon</td><td>No data</td><td>5 times for each of all fixtures</td></tr>
<tr><td rowspan="3">Water-flow Meter</td><td rowspan="3">No data</td><td>5 times for each of all fixtures with plug</td><td rowspan="2">5 times for each of all fixtures with plug or balloon</td><td rowspan="2">10 times for each of selected 4 fixtures with plug or balloon</td></tr>
<tr><td>5 times for each of all fixtures with balloon</td></tr>
<tr><td>5 times for each of all fixtures without measurement</td><td>5 times for each of all fixtures without measurement</td><td>10 times for each of selected 8 fixtures without measurement</td></tr>
</table>

PILOT TEST: AS-IS PHASE OF URINALS

First, the researcher conducted a pilot test on urinals (02/08/2002~02/28/2002, 04/18/2002~05/08/2002).

a. The experimental objects were made up of twelve urinals (1.5 gpf) in an unmodified condition (as-is). The researcher directly measured the water-volume per flush with the plug method and repeated it ten times for each of all the fixtures in the restrooms of the Langford Architecture building A.

Findings in the Pilot Test: As-is Phase

a. There was a significant difference between directly measured values and the standard. The measured mean, 0.276 gpf, was much less than the standard 1.5 gpf (see Table 34). It was because the plug measurement method did not stop up one of the waterways in a urinal—one waterway was located in back. Finally, the balloon measurement method was suggested to solve the problem.

Table 34

Descriptive statistics - as-is phase of urinals

		Statistic
As-is_Ur	Mean	.2758
	Median	.2213
	Variance	.019
	Std. Deviation	.13756
	Minimum	.12
	Maximum	.63
	Range	.51

b. Some values had considerable differences with the others (see Figure 23). The result was assumed because original fixtures had not been on a timely management service. Finally, the researcher decided to tune up the original fixtures to secure managed status.

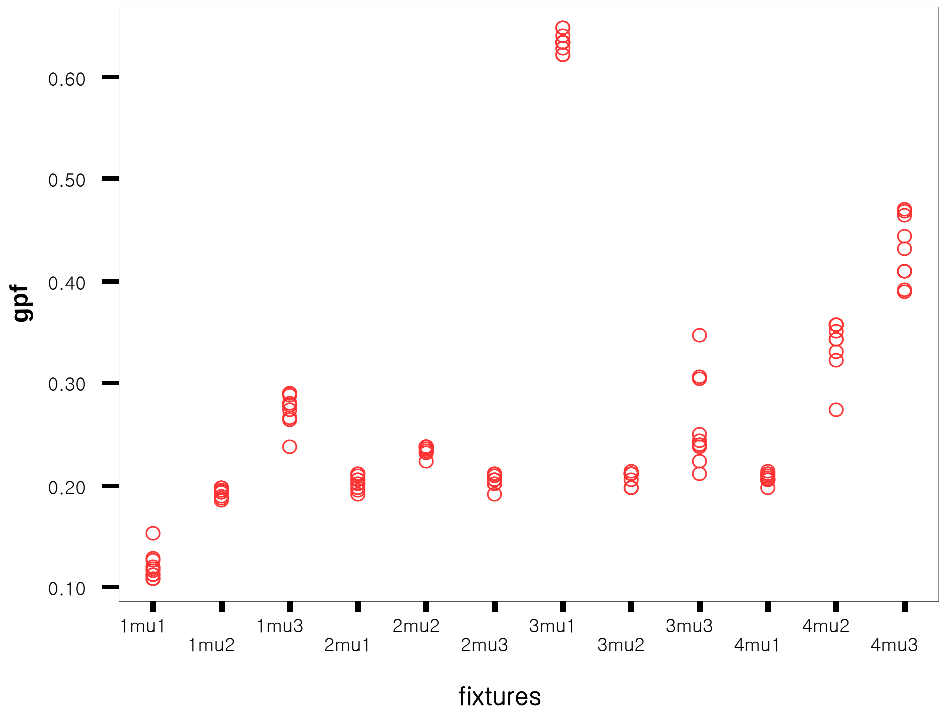

Figure 23: Scatter plot - measured data (plug method)

c. In the as-is phase, the plug measurement method was not correct, and the balloon method that could measure the actual water-volume was not applied. Therefore, to predict the values with the balloon method in the as-is phase, an equation, Predicted Balloon as-is = 0.88 + 2.13 * Plug as-is, was applied—the regression procedure was explained in the tune-up phase of urinals. Table 35 shows the predicted result of as-is phase.

Table 35

Descriptive statistics - measured data (balloon method)

		Statistic
As-is_ Balloon_ Urinal	Mean	1.4630
	Median	1.3468
	Variance	.086
	Std. Deviation	.29327
	Minimum	1.13
	Maximum	2.23
	Range	1.09

d. The predicted mean, 1.4630 gpf, in the as-is phase of urinals was less than the standard 1.5 gpf (see Table 35). However, statistically, there was no significant difference between the predicted mean and the standard. To compare them, a one sample T-test was conducted:

H_o : µ as-is = 1.5 gpf,

H_a : µ as-is $\neq$ 1.5 gpf.

The null hypothesis was accepted because p-value (.157) > .05 (see Table 36).

Table 36

T-Test - measured data (balloon method) vs. standard (1.5 gpf)

	Test Value = 1.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
as-is Ur	-1.426	119	.157	-.0370	-.0885	.0144

e. To define another measure of variability, coefficient of variation (CV) was applied. The coefficient of variation (CV) measures the variability in the values in a population relative to the magnitude of the population mean. Thus, the CV is the standard deviation of the population expressed in units of μ.

Coefficient of variation (CV) of the predicted values was 20.048 %:

CV = 100 (s / $|\bar{y}|$)% = 100 (0.2933 / 1.4630)%.

Moreover, there were some problem values (Figure 23).

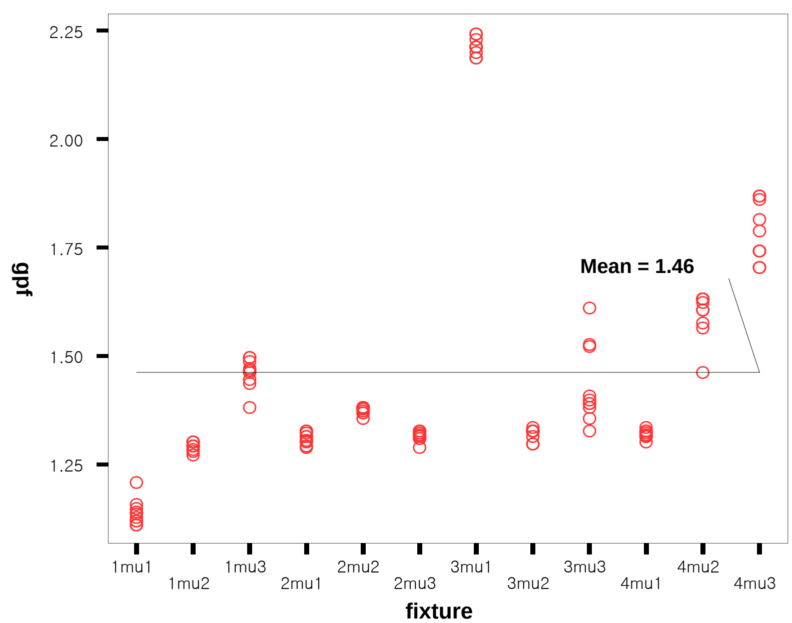

Figure 24: Scatter plot - measured data (balloon method)

f. After the as-is phase, a water-flow meter, Rosemont 8705, was installed to obtain reliable data in basement of the Langford Architecture building A.

TUNE-UP PHASE OF URINALS

Second, the researcher collected data on the tune-up phase of the urinals (9/26/2002~ 10/09/2002).

a. New diaphragms, handles, and vacuum breakers were installed in the original valves of all urinals. However, chinas and other plumbing systems had same status as the as-is phase, and the standard of the urinals, 1.5 gpf, was also the same.

b. The researcher measured the actual water-volume per flush with plug and balloon methods and repeated it five times for all twelve fixtures. At the same time, the water meter was read.

c. Additionally, the water meter was read five times per each for all twelve fixtures, when the plug or balloon method was not applied to china, to analyze whether the measurement methods were effective in measuring meter values.

Findings in Tune-up Phase

a. There was a significant difference between the two means of directly measured values with plug and balloon methods in the tune-up phase (see Table 37 and Table 38). The mean (0.2521 gpf) measured with the plug method was around 17.85% of the mean (1.4125 gpf) measured with the balloon method. It meant that the plug method missed a lot of water. However, the balloon method was reliable because it could stop up the all waterways of the urinals perfectly.

Table 37

Descriptive statistics - tune-up phase of urinals (plug method)

		Statistic
Tuneup _Plug_Ur	Mean	.2521
	Median	.2071
	Variance	.013
	Std. Deviation	.11311
	Minimum	.13
	Maximum	.50
	Range	.37

Table 38

Descriptive statistics - tune-up phase of urinals (balloon method)

		Statistic
Tuneup _Ball_Ur	Mean	1.4125
	Median	1.3871
	Variance	.114
	Std. Deviation	.33824
	Minimum	.73
	Maximum	2.02
	Range	1.29

b. The mean, 1.41 gpf, measured with the balloon method was less than the standard 1.5 gpf (see Table 38). Moreover, statistically, there was a significant difference between the mean and the standard. To compare them, a one sample T-test was conducted:

H_o : µ tune-up_balloon = 1.5 gpf,

H_a : µ tune-up_balloon $\neq$ 1.5 gpf.

The null hypothesis was rejected because p-value (.048) < .05 (see Table 39).

Table 39

T-Test - measured data (balloon method) vs. standard (1.5 gpf)

	Test Value = 1.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
tune-up Ur	-2.016	59	.048	-.0876	-.1745	-.0006

c. The values measured with the balloon method had considerable differences between the fixtures (Figure 24). Coefficient of variation (CV), 23.946 %, was more than as-is phase:

CV = 100 (s / $|\bar{y}|$)% = 100 (0.3382 / 1.4125)%.

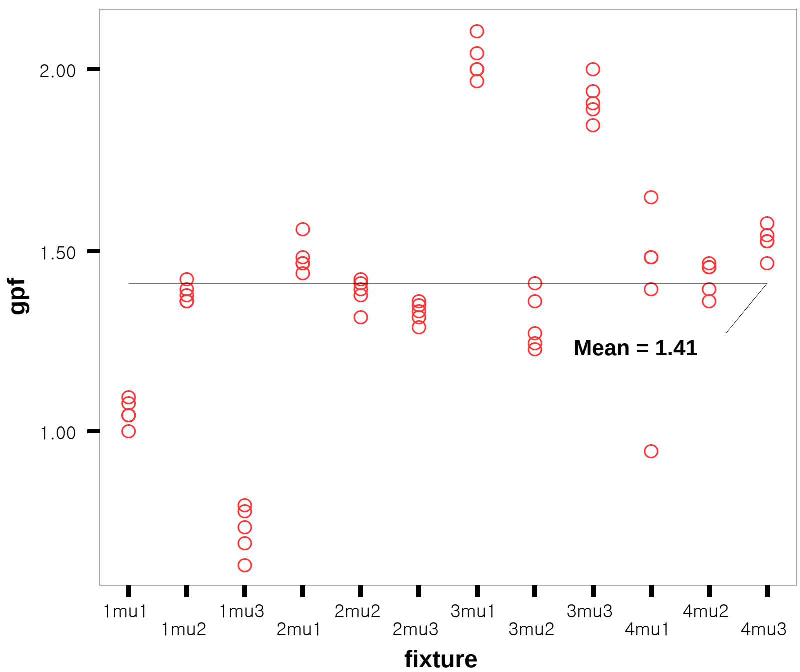

Figure 25: Scatter plot - measured data (balloon method)

d. Even though the plug method was not correct, it was reliable in measuring the water-volume per flush. Figure 26 shows that the values measured with the plug method have similar graphs to the values measured with the balloon method in the tune up phase. Therefore, it was assumed that there was a relationship between the values measured with both plug and balloon methods.

The regression model between balloon and plug methods in the tune-up phase of urinals was Balloon tune-up = Bo + B1 Plug tune-up = 0.88 + 2.13 * Plug tune-up (see Figure 27 and Table 40). The test results of the model were acceptable (see Table 41 and 42). Residual was also normally distributed (Figure 28 and Table 43).

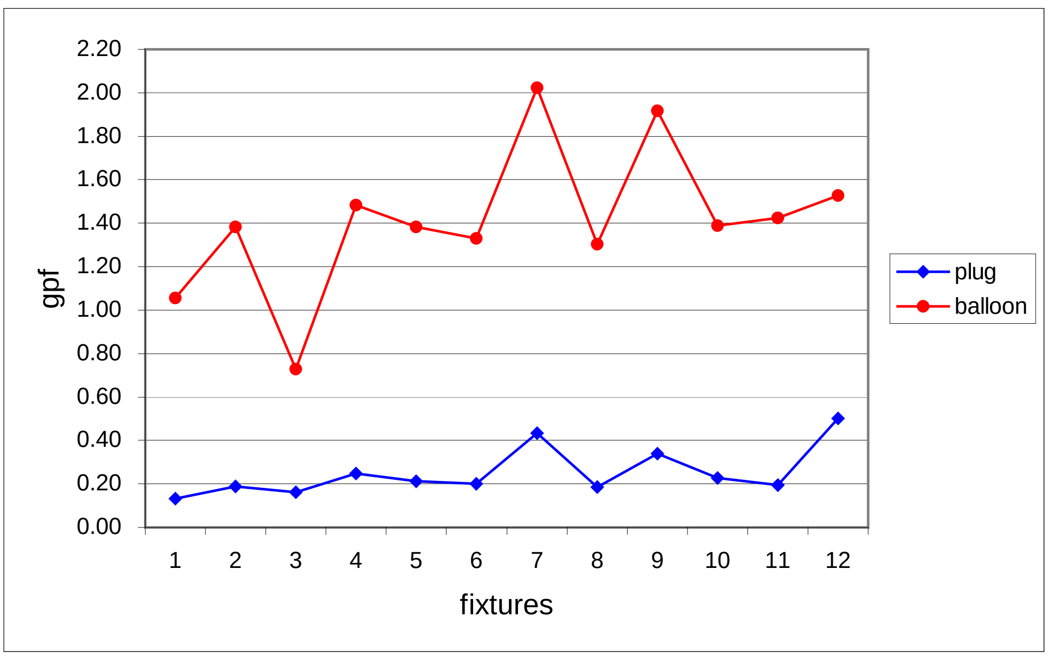

Figure 26: Graph - balloon vs. plug methods

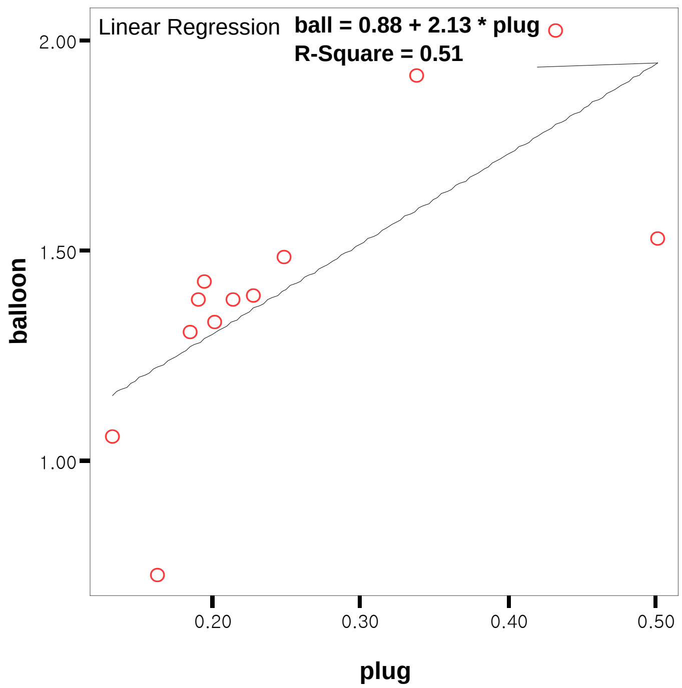

Figure 27: Scatter plot - balloon vs. plug methods

Table 40

Coefficients - balloon vs. plug methods

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.875	.182		4.810	.001
	PLUG	2.132	.663	.713	3.215	.009

Table 41

Model summary - balloon vs. plug methods

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.713[a]	.508	.459	.24877

a. Predictors: (Constant), PLUG

Table 42

ANOVA table - balloon vs. plug methods

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.640	1	.640	10.335	.009[a]
	Residual	.619	10	.062		
	Total	1.258	11			

a. Predictors: (Constant), PLUG

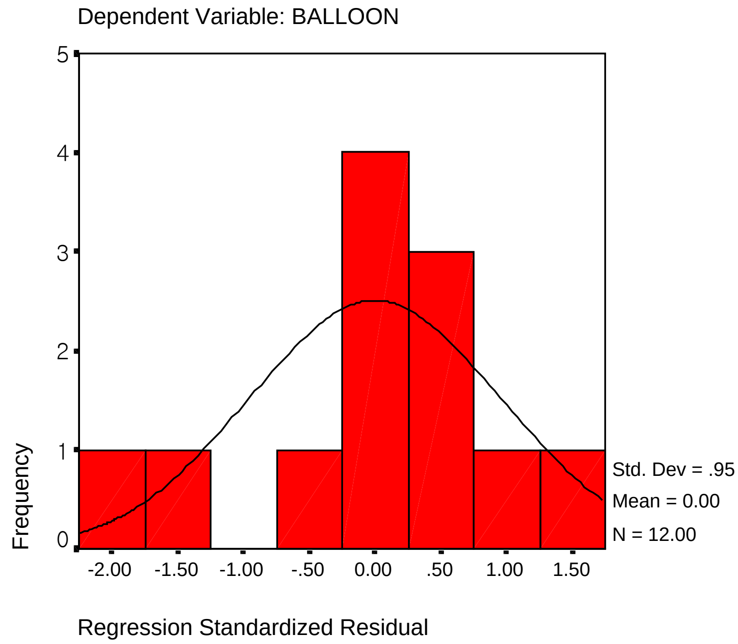

Figure 28: Residual histogram - balloon vs. plug methods

Table 43

Normality test - balloon vs. plug methods

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Standardized Residual	.293	12	.005	.862	12	.052

a. Lilliefors Significance Correction

e. Basically, both the as-is and tune-up phases had the same chinas, valves (1.5 gpf), and plumbing systems. Therefore, it was assumed that the relationship between values measured with the plug and balloon methods in the as-is phase was the same as the relationship in the tune-up phase. Finally, to predict the data measured with the balloon method in as-is urinals, the regression model in the tune-up phase was applied. The equation, Predicted Balloon as-is = 0.88 + 2.13 * Plug as-is, was applied.

f. The mean of the water meter, 1.204 gpf, was less than the directly measured mean, 1.413 gpf, with balloon methods because the water meter was not sensitive to small water volume (see Table 44). To prove it, A paired T-test was conducted,

H_o : µ meter with balloon = µ balloon,

H_a : µ meter with balloon $\neq$ µ balloon.

The null hypothesis was rejected because p-value (.000) < .05 (see Table 45).

Therefore, the water meter was not appropriate as a measurement method.

Table 44

Descriptive statistics - water meter with balloon method

		Statistic
MET_BALL	Mean	1.2035
	Median	1.2210
	Variance	.109
	Std. Deviation	.33074
	Minimum	.51
	Maximum	1.76
	Range	1.25

Table 45

Paired T-test - water meter vs. measured data (balloon method)

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Meter − Balloon	−.2089	.05849	.01688	−.2461	−.1718	−12.4	11	.000

g. However, the water meter was reliable in measuring the water-volume per flush. Figure 29 shows that meter and values measured with the balloon method in the tune-up phase have similar graphs—they are moving together in a constant rate. Moreover, a regression model showed that they had a relationship (see Figure 30 and Table 46). The regression model had a high R-square and the test results were acceptable (see Table 47 and 48)

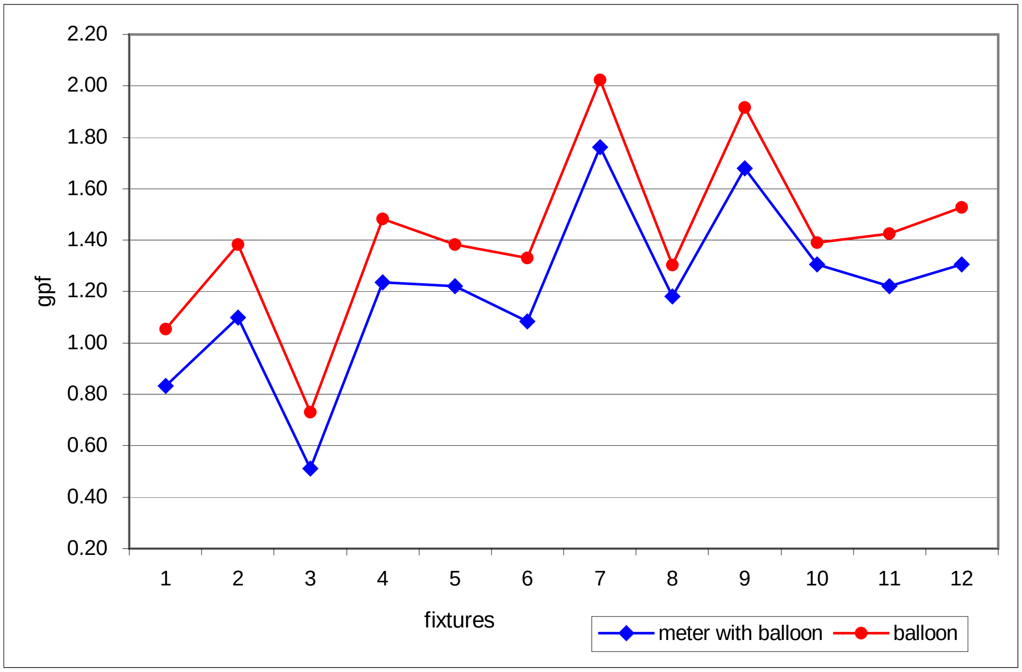

Figure 29: Graph - water meter vs. measured data (balloon method)

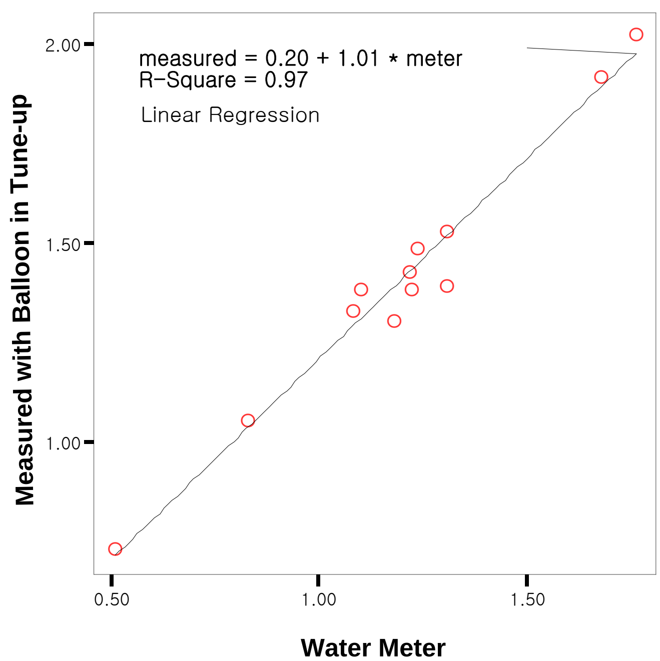

Figure 30: Scatter plot - water meter vs. measured data (balloon method)

Table 46

Coefficients - water meter vs. measured data (balloon method)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.200	.070		2.879	.016
	MET_BALL	1.007	.056	.985	18.027	.000

Table 47

Model summary - water meter vs. measured data (balloon method)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.985[a]	.970	.967	.06129

a. Predictors: (Constant), MET_BALL

Table 48

ANOVA table - water meter vs. measured data (balloon method)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.221	1	1.221	324.978	.000[a]
	Residual	.038	10	.004		
	Total	1.258	11			

a. Predictors: (Constant), MET_BALL

h. There was no difference between results with and without measurement methods in the water meter. Therefore, the test with plug or balloon method had no effect on the value of the water meter. To prove it, a Bonferroni test was conducted:

H_o : µ meter only = µ meter with plug = µ meter with balloon,

H_a : at least one of the means differs from rest.

The null hypothesis was accepted (see Table 49).

Table 49

Bonferroni test - with and without methods in water meter

Dependent Variable: METER
Bonferroni

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	.0082	.14161	1.000	-.3490	.3653
	3.00	.0000	.14161	1.000	-.3572	.3572
2.00	1.00	-.0082	.14161	1.000	-.3653	.3490
	3.00	-.0082	.14161	1.000	-.3653	.3490
3.00	1.00	.0000	.14161	1.000	-.3572	.3572
	2.00	.0082	.14161	1.000	-.3490	.3653

1: meter only, 2: meter with plug, 3: meter with balloon

LOW-MANUAL PHASE IN URINALS

Third, the researcher collected data on the low-manual phase of urinals (10/14/2002~ 10/27/2002).

a. New low-consumption manual valves and chinas were installed in the restrooms of the Langford Architecture building A. However, other plumbing systems had the same status as before. They all had the same shape of china and the same type of valves, and the standard of urinals was 1.0 gpf. Furthermore, all waterways of new china could be stopped up with both plug and balloon measurement methods.

b. The researcher measured the actual water-volume per flush with the plug or balloon methods and repeated it five times for all twelve fixtures. At the same time, the water meter was read.

c. Additionally, the water meter was read five times for all twelve fixtures, when the measurement method was not applied to china, in order to analyze whether the method was effective in measuring meter values.

Findings in Low-manual Phase

a. The mean, 0.670 gpf, in the low-manual phase of the urinals was less than the standard 1.0 gpf (see Table 50). Moreover, statistically, there was a significant difference between the mean and the standard. To compare them, one sample T-test was conducted:

H_o : µ low-manual = 1.0 gpf,

H_a : µ low-manual $\neq$ 1.0 gpf.

The null hypothesis was rejected because p-value (.000) < .05 (see Table 51).

Table 50

Descriptive statistics - low-manual phase of urinals

		Statistic
Lowmanual _Urinal	Mean	.6703
	Median	.6451
	Variance	.004
	Std. Deviation	.06685
	Minimum	.60
	Maximum	.82
	Range	.21

Table 51

T-test - measured data vs. standard (1.0 gpf)

	Test Value = 1.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Low-manual Ur	-35.944	59	.000	-.3297	-.3480	-.3113

b. Coefficient of variation (CV) of the low-manual phase was 9.973 %:

CV = 100 (s / $|\bar{y}|$)% = 100 (0.0669 / 0.6703)%.

It was quite less than the as-is and tune-up phases, and Figure 31 shows that the difference between the fixtures is not significant.

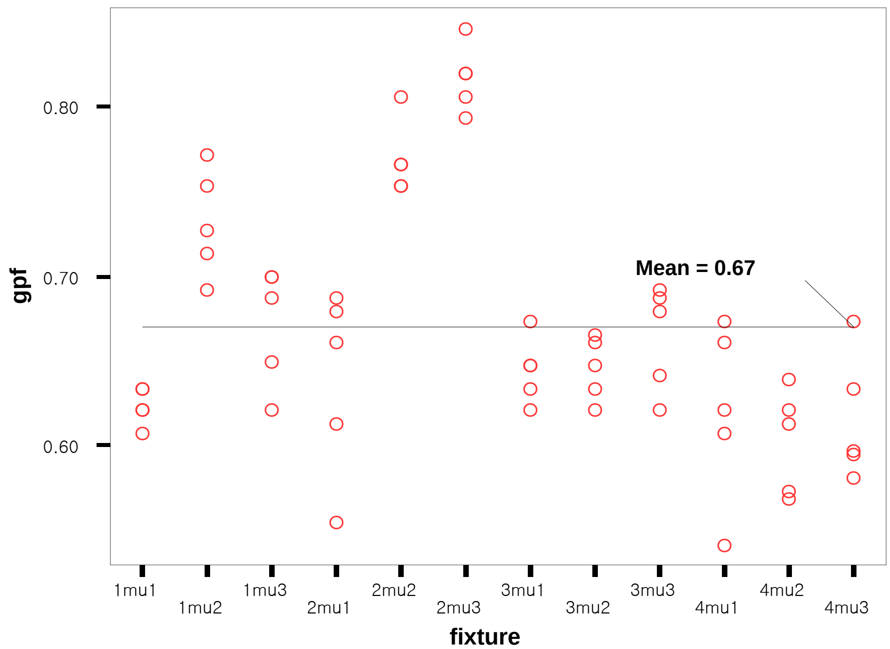

Figure 31: Scatter plot – measured data (balloon method)

c. The mean of the water meter (0.487 gpf) was less than the directly measured mean (0.670 gpf) with plug and balloon methods—it is the same result as in the tune-up phase (see Table 52). A paired T-test was conducted:

H_o : µ meter = µ measure,

H_a : µ meter $\neq$ µ measure.

The null hypothesis was rejected because p-value (.000) < .05 (see Table 53). Therefore, the water meter was not appropriate as a measurement method.

Table 52

Descriptive statistics - water meter

		Statistic
METER	Mean	.4867
	Median	.4750
	Variance	.004
	Std. Deviation	.06184
	Minimum	.40
	Maximum	.59
	Range	.19

Table 53

Paired T-test - water meter vs. measured data

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
METER − MEASURED	−.1833	.03420	.00987	−.2051	−.1616	−18.569	11	.000

d. However, the water meter was reliable in measuring the water-volume per flush. Figure 32 shows that the water meter and measured values in the low-manual phase have similar graphs—it is the same result as in the tune-up phase. The meter values and the measured values are moving together in a constant rate. Moreover, a regression model showed that they had a relationship (see Figure 33 and Table 54). The results of the model were acceptable (see Table 55 and 56)

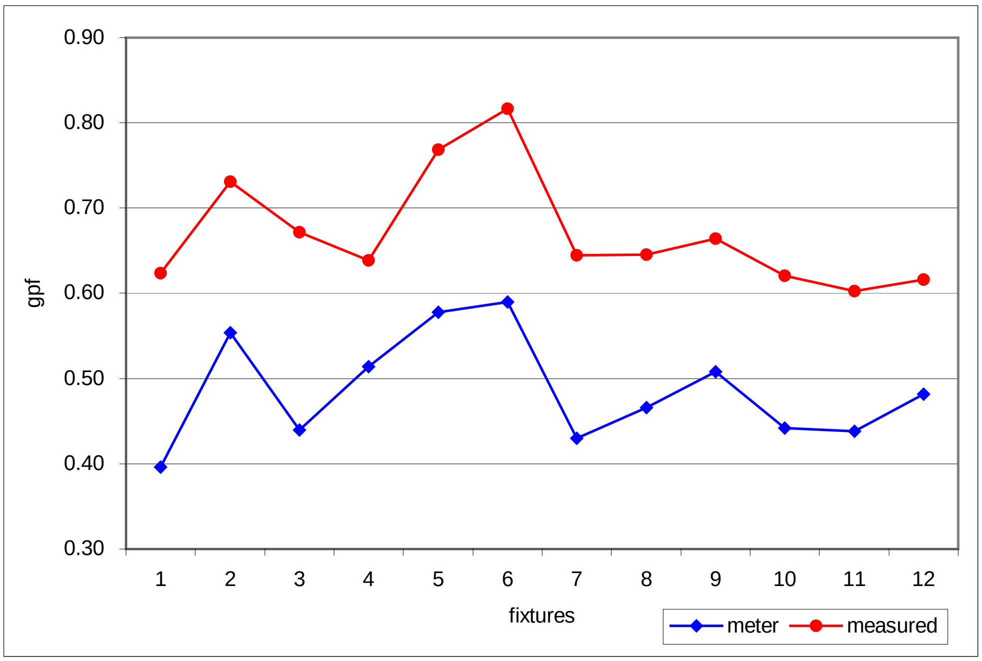

Figure 32: Graph - water meter vs. measured data

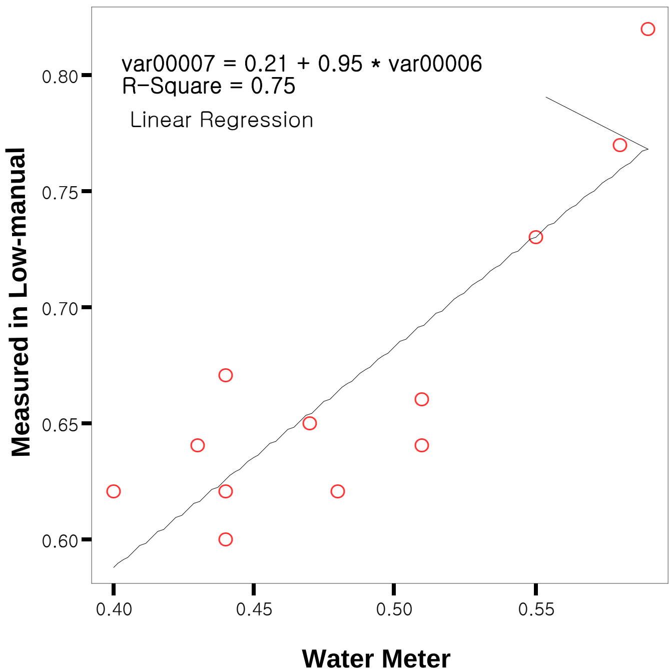

Figure 33: Scatter plot - water meter vs. measured data

Table 54

Coefficients - water meter vs. measured data

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.207	.085		2.427	.036
	METER	.951	.174	.865	5.459	.000

Table 55

Model summary - water meter vs. measured data

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.865[a]	.749	.724	.03573

a. Predictors: (Constant), METER

Table 56

ANOVA table - water meter vs. measured data

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.038	1	.038	29.796	.000[a]
	Residual	.013	10	.001		
	Total	.051	11			

a. Predictors: (Constant), METER

e. There was no difference between results with and without measurement methods in the water meter. Therefore, the test with plug or balloon method had no effect on the value of the water meter—it is the same result as in the tune-up phase. A paired T-test was conducted:

H_o : µ meter only = µ meter with measurement,

H_a : µ meter only $\neq$ µ meter with measurement.

The null hypothesis was accepted because p-value (.534) > .05 (see Table 57).

Table 57

T-test - with and without methods in water meter

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Meter Only – With Measure	−.0048	.05979	.00772	−.0203	.0106	−.626	59	.534

LOW-AUTOMATIC PHASE OF URINALS

Fourth, the researcher collected data on the low-automatic phase of urinals (11/11/2002~ 11/26/2002).

a. New low-consumption automatic valves were installed on the chinas in the low-manual phase instead of low-consumption manual valves. However, chinas and other plumbing systems had the same status as the low-manual phase. They all had the same shape of china and the same type of valves, and the standard of the urinals was 1.0gpf.

b. The researcher measured the actual water-volume per flush with plug or balloon methods and repeated it ten times for randomly selected four fixtures. At the same time, the water meter was read.

c. The water meter was read ten times for eight fixtures that were not directly measured, when the plug or balloon method was not applied to china, in order to expect directly measured values.

<u>Findings in Low-automatic Phase</u>

a. It was proven that there was a relationship between the water meter and measured values in the tune-up and low-manual phases. To predict the measured values of the eight fixtures that were not measured directly, the researcher conducted a regression between the directly measured four fixtures and the water meter.

The regression model was

Measure low-auto = Bo + B1 * Meter low-auto

= 1.064 – 0.137 * Meter low-auto (see Figure 34 and Table 58).

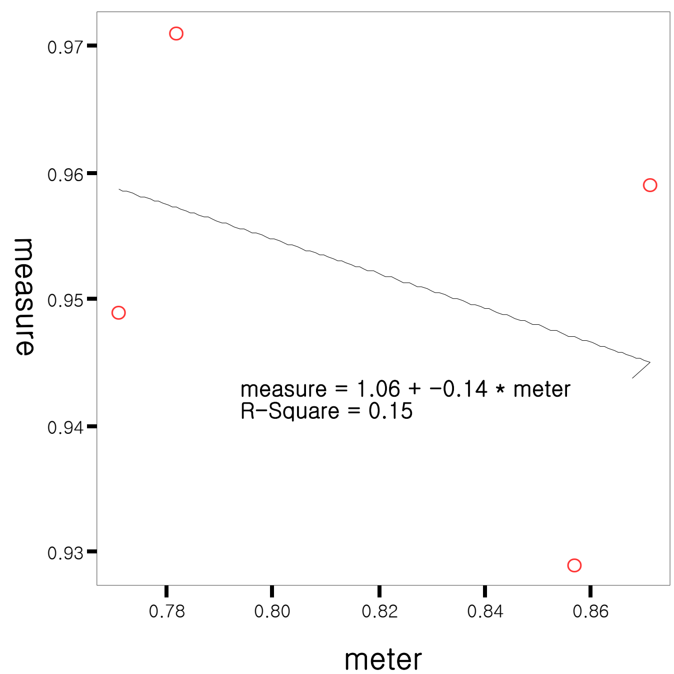

Figure 34: Scatter plot - water meter vs. measured data

Table 58

Coefficients - water meter vs. measured data

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	1.064	.186		5.720	.029
METER	−.137	.226	−.393	−.604	.607

Table 59

Model summary - water meter vs. measured data

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.393[a]	.154	−.269	.02002

a. Predictors: (Constant), METER

Table 60

ANOVA table - water meter vs. measured data

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.000	1	.000	.365	.607[a]
Residual	.001	2	.000		
Total	.001	3			

a. Predictors: (Constant), METER

The regression model had a low R-square (see Table 59) and the regression results were not good (see Table 58 and Table 60). Figure 35 and Table 61 shows the normality test of residual. It was inferred that small sample size caused the problem. However, the equation was acceptable because, obviously, it was proven that there was a relationship between the water meter and measured values in the other phases

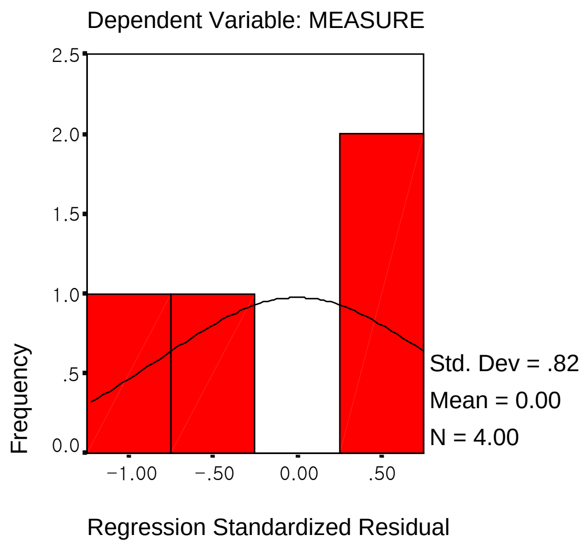

Figure 35: Residual histogram - water meter vs. measured data

Table 61

Normality test - water meter vs. measured data

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Standardized Residual	.300	4	.	.833	4	.176

a. Lilliefors Significance Correction

b. The mean, 0.9783 gpf, in the low-automatic phase was less than the standard 1.0 gpf (see Table 62). Statistically, there was a significant difference between the mean and the standard. To compare them, a one sample T-test was conducted:

H_o : µ low-auto = 1.0 gpf,

H_a : µ low-auto $\neq$ 1.0 gpf.

The null hypothesis was rejected because p-value (.037) < .05 (see Table 63).

Table 62

Descriptive statistics - low-automatic phase of urinals

		Statistic
LOWAUTO	Mean	.9783
	Median	.9710
	Variance	.001
	Std. Deviation	.03161
	Minimum	.93
	Maximum	1.03
	Range	.10

Table 63

T-test - measured data vs. standard (1.0 gpf)

	Test Value = 1.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Low-Auto Ur	-2.374	11	.037	-.0217	-.0418	-.0016

c. Figure 36 shows the difference between the fixtures, and coefficient of variation (CV), 3.230 %, is the lowest value in the urinal phases:

CV = 100 (s / $|\bar{y}|$)% = 100 (0.0316 / 0.9783)%.

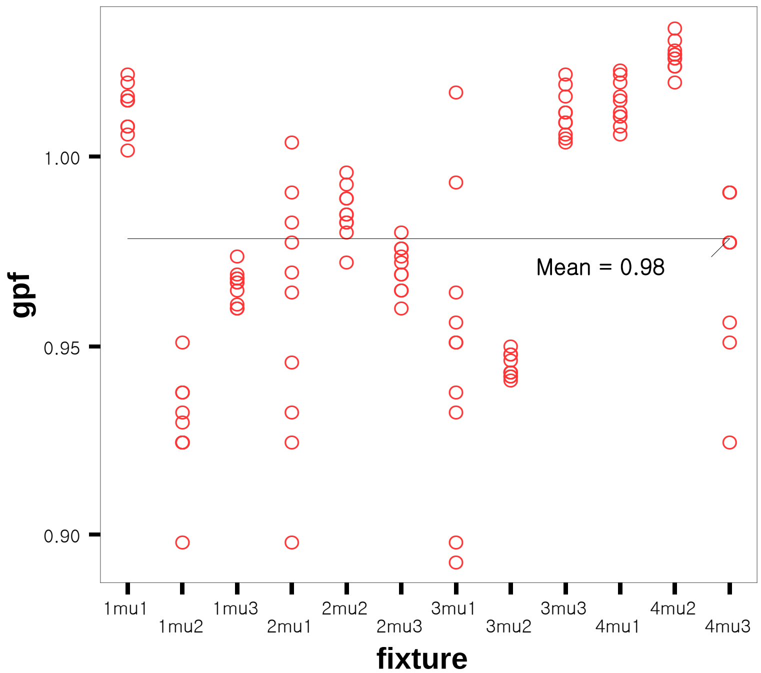

Figure 36: Scatter plot - measured data

SUMMARY OF URINALS

a. The researcher compared the water-volume per flush of all phases in the urinals. Figure 37 shows the means in the urinals. The result of the mean values is

As-is (1.463 gpf) > Tune-up (1.413 gpf) > Low-auto (0.978 gpf) > Low-manual (0.670 gpf).

Table 64 shows the comparative water-volume of other phases when it is assumed that the mean of as-is phase is 100%.

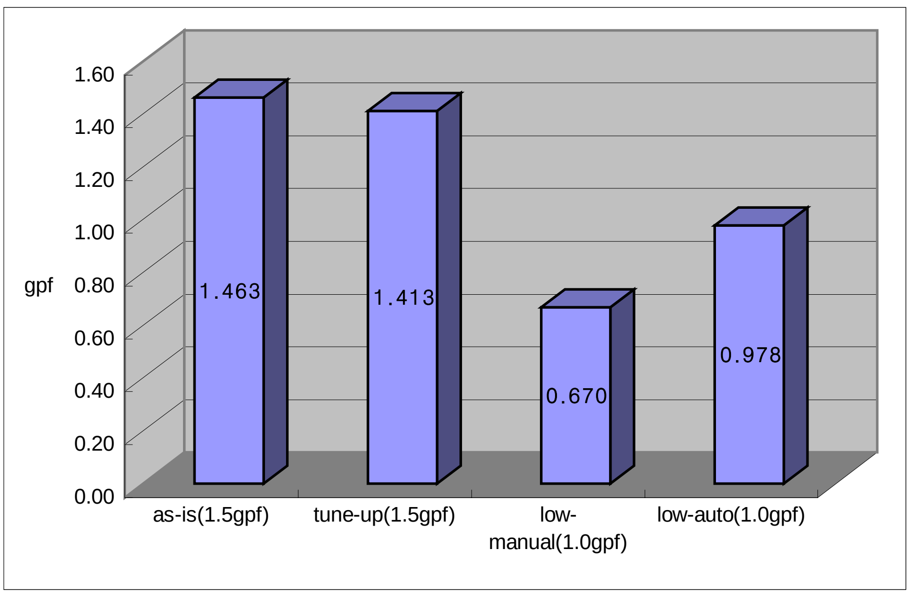

Figure 37: Graph - measured means in urinals

Table 64

As-is vs. comparative values of other phases in urinals

Phase	**As-is**	**Tune-up**	**Low-manual**	**Low-auto**
Mean	1.463 gpf	1.413 gpf	0.670 gpf	0.978 gpf
Each / As-is (%)	**100 %**	**96.58 %**	**45.80 %**	**66.85 %**

b. However, statistical analysis has a different result.

A Bonferroni test was conducted:

H_o : µ as-is = µ tune-up = µ low-manual = µ low-auto,

H_a : at least one of the means differs from rest.

The null hypothesis was rejected (see Table 65).

The result of statistics analysis is

As-is = Tune-up > Low-automatic > Low-manual.

Table 65

Bonferroni test - urinals

Dependent Variable: DATA
Bonferroni

(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	.0506	.09262	1.000	-.2053	.3065
	3.00	.7927*	.09262	.000	.5368	1.0486
	4.00	.4847*	.09262	.000	.2288	.7406
2.00	1.00	-.0506	.09262	1.000	-.3065	.2053
	3.00	.7421*	.09262	.000	.4862	.9980
	4.00	.4341*	.09262	.000	.1782	.6900
3.00	1.00	-.7927*	.09262	.000	-1.0486	-.5368
	2.00	-.7421*	.09262	.000	-.9980	-.4862
	4.00	-.3080*	.09262	.011	-.5639	-.0521
4.00	1.00	-.4847*	.09262	.000	-.7406	-.2288
	2.00	-.4341*	.09262	.000	-.6900	-.1782
	3.00	.3080*	.09262	.011	.0521	.5639

*. The mean difference is significant at the .05 level.

1: As-is, 2: Tune-up, 3: Low-manual, 4:Low-automatic

c. Most phases of the urinals have different actual water-volumes than their standards (see Figure 38). The tune-up, low-manual, and low-automatic phases show significant differences between the standards and the actual water-volumes of flushing (see Table 66).

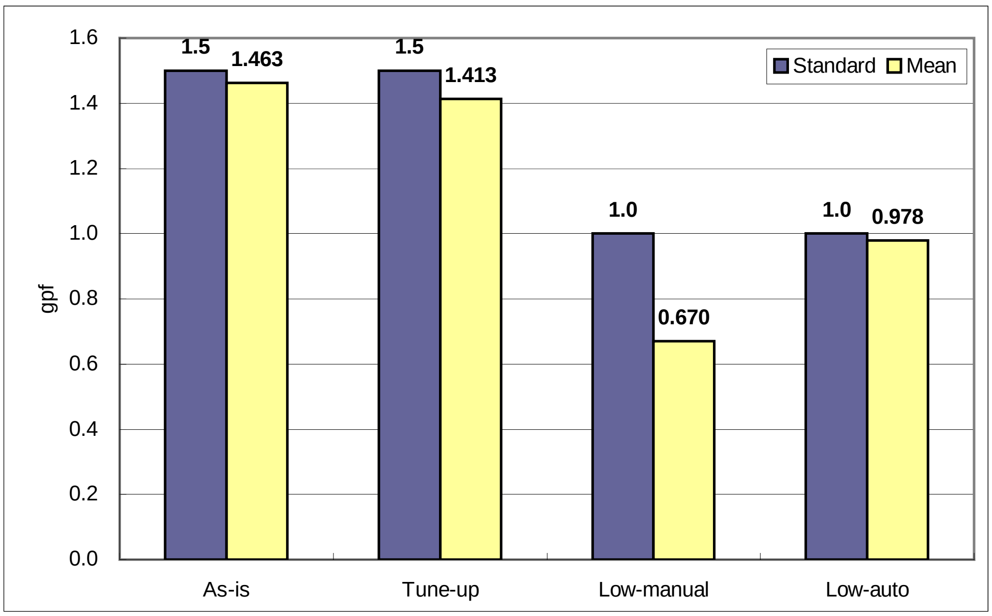

Figure 38: Graph - measured mean vs. standard in urinals

Table 66

The standard vs. measured means in urinals

Phase	As-is	**Tune-up**	**Low-manual**	**Low-auto**
Mean	1.463 gpf	**1.413 gpf**	**0.670 gpf**	**0.978 gpf**
Standard	1.5 gpf	**1.5 gpf**	**1.0 gpf**	**1.0 gpf**
Mean / Std. (%)	97.53 %	**94.20 %**	**67.00 %**	**97.83 %**
Sig. *(2-tailed)*	.157	**.048**	**.000**	**.037**

d. There is a tendency in the low-consumption fixtures to have a lower coefficient of variance (CV). New fixtures in the low-manual and low-automatic phases have a low CV but old fixtures in the as-is and tune-up phases have high rate (see Figure 39 and Table 67). It is assumed that the results are related to the management status of the fixtures.

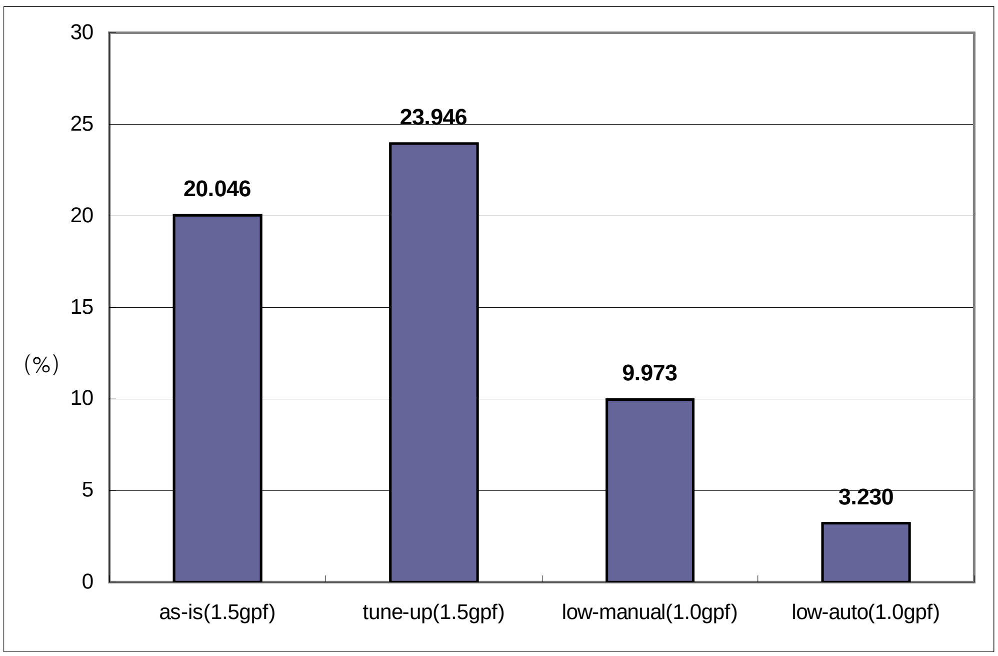

Figure 39: Graph - coefficient of variance in urinals

Table 67

Coefficient of variance in urinals

Phase	As-is	Tune-up	Low-manual	Low-auto
Std. Deviation	0.2933	0.3382	0.0669	0.0316
Mean	1.463 gpf	1.413 gpf	0.670 gpf	0.978 gpf
CV	**20.046 %**	**23.946 %**	**9.973 %**	**3.230 %**

CONCLUSIONS

The researcher directly measured the actual water-volumes (gpf) of the as-is, tune-up, low-consumption manual, and low-consumption automatic water closets and urinals applied to the restrooms of the Langford Architecture building A. Consequently, some results were found.

a. First, there are significant differences between the standards and the actual water-volumes—directly measured means (see Table 68). It means that other studies using the standards are not correct. Therefore, this study provides practical and precise standards of water closets and urinals.

Table 68

The standards vs. actual water-volumes

	Phase	As-is	Tune-up	Low-manual	Low-auto
Water closet	Mean	**3.305 gpf**	**4.174 gpf**	1.599 gpf	**1.980 gpf**
	Standard	**3.5 gpf**	**4.5 gpf**	1.6 gpf	**1.6 gpf**
Urinal	Mean	1.463 gpf	**1.413 gpf**	**0.670 gpf**	**0.978 gpf**
	Standard	1.5 gpf	**1.5 gpf**	**1.0 gpf**	**1.0 gpf**

b. Second, Figure 40 shows that the actual water-volumes of the low consumption fixtures are much less than those of the old (high-consumption) fixtures. Moreover, there is no significant difference, statistically, between the low-manual and low-automatic phases in water closets even though the mean of the low-manual phase is less than the low-automatic phase's (see Table 69).

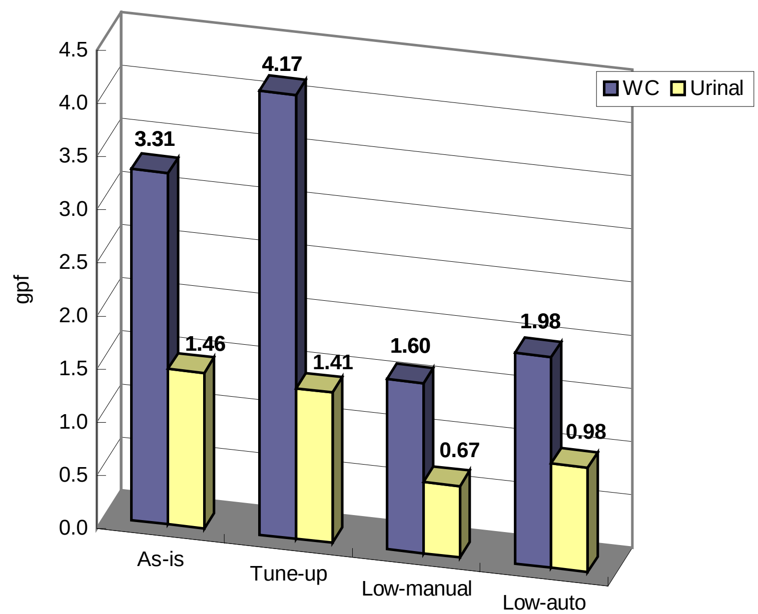

Figure 40: Graph - actual water-volumes

Table 69

The experiment result of the actual water-volumes (gpf)

WC	Mean	Tune-up > As-is > Low-auto > Low-manual
	Bonferroni	Tune-up > As-is > Low-manual = Low-automatic
Urinal	Mean	As-is > Tune-up > Low-auto > Low-manual
	Bonferroni	As-is = Tune-up > Low-automatic > Low-manual

c. Third, Table 70 shows the water-volumes (gpf) of other phases compared to the as-is phase when it is assumed that the mean of the as-is phase is 100%. Accordingly, this study presents that retrofitting an original water closet (3.5 gpf) with a low-consumption fixture (1.6 gpf) can save water-cost up to 51.62 %, and retrofitting an original urinal (1.5 gpf) with a low-consumption (1.0 gpf) fixture can save water-cost up to 50.44 %.

Table 70

As-is vs. comparative values of other phases

	Phase	As-is	Tune-up	Low-manual	Low-auto
WC	Standard	3.5 gpf	4.5 gpf	1.6 gpf	1.6 gpf
	Mean	**3.305 gpf**	**4.174 gpf**	**1.599 gpf**	**1.980 gpf**
	Comparative	**100 %**	**126.29 %**	**48.38 %**	**59.91 %**
Urinal	Standard	1.5 gpf	1.5 gpf	1.0 gpf	1.0gpf
	Mean	**1.463 gpf**	**1.413 gpf**	**0.670 gpf**	**0.978 gpf**
	Comparative	**100 %**	**96.58 %**	**45.80 %**	**66.85 %**

Finally, this study provides the actual water-consumptions (gpf) of sanitary fixtures and proves that retrofitting with low-consumption fixtures can save on water costs. The results will present practical standards to facility managers and other building professionals and will also contribute to determining the availability of retrofitting water closets and urinals.

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APPENDIX A

DEFINITION

Flushometer-valve toilet

A tankless toilet with the flush valve attached to a pressurized water supply pipe. When activated, the connecting pipe supplies water to the toilet at a flow rate necessary to flush waste into the sewer

GPCD Gallons per capita per day

GPD Gallons per day

GPF Gallons per flush

Gravity-flush toilet

A toilet with a rubber stopper (flapper valve) that releases water from the toilet tank, after which gravity forces the contents of the toilet bowl through a trap way for discharge into the wastewater system

Low-consumption water closet

A toilet that uses no more than 1.6 gallons per flush; also referred as low-flow toilet

Low-consumption urinal

A urinal that uses no more than 1.0 gallon per flush; also referred as low-flow urinal

Water meter

An instrument that measures water use; often installed by a water utility to measure end uses, such as uses by a household, building facility, or irrigation system

Retrofit

To change, alter, or adjust plumbing fixtures or other equipment or appliances to save water or make operate more efficiently.

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